NEW

HOW IT WORKS

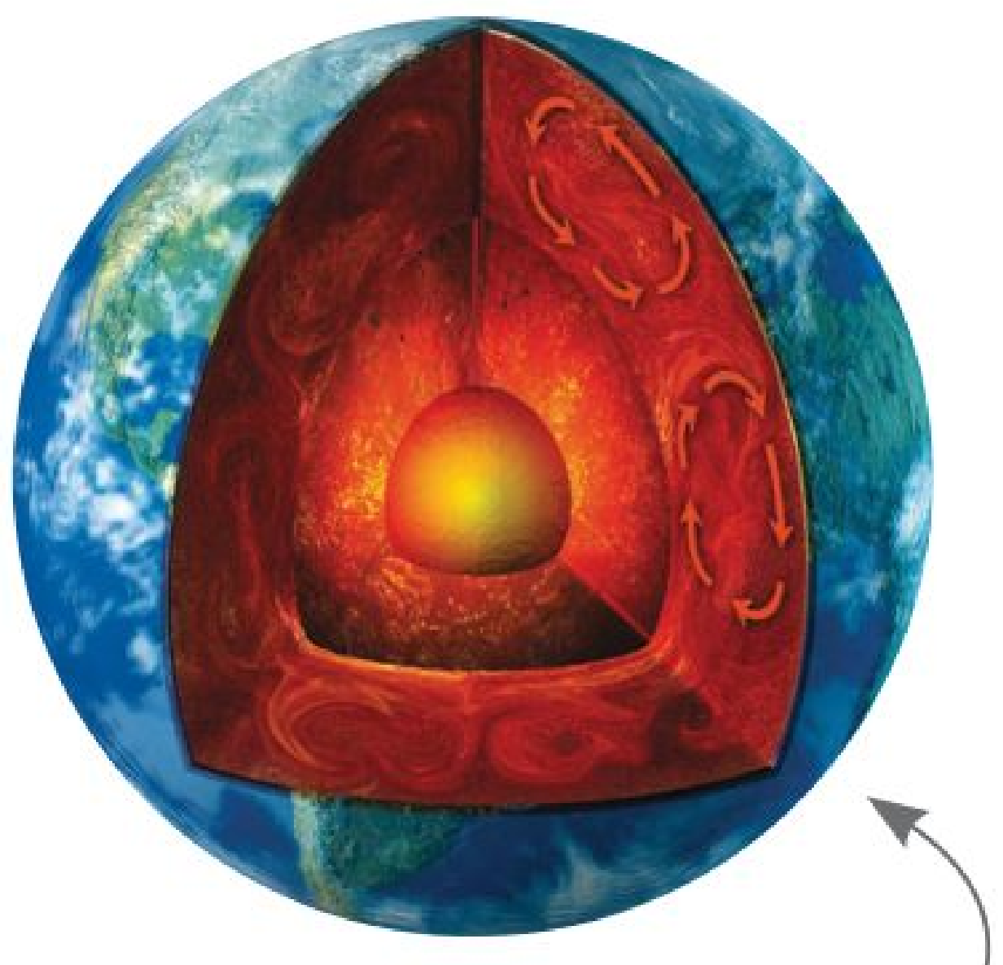
AMAZING CUTAWAYS

DISCOVER THE INNER WORKINGS OF THE WORLD'S WONDERS

Inside a Red Arrow

How do tigers hunt their prey?

OVER 50 INCREDIBLE CUTAWAYS INSIDE

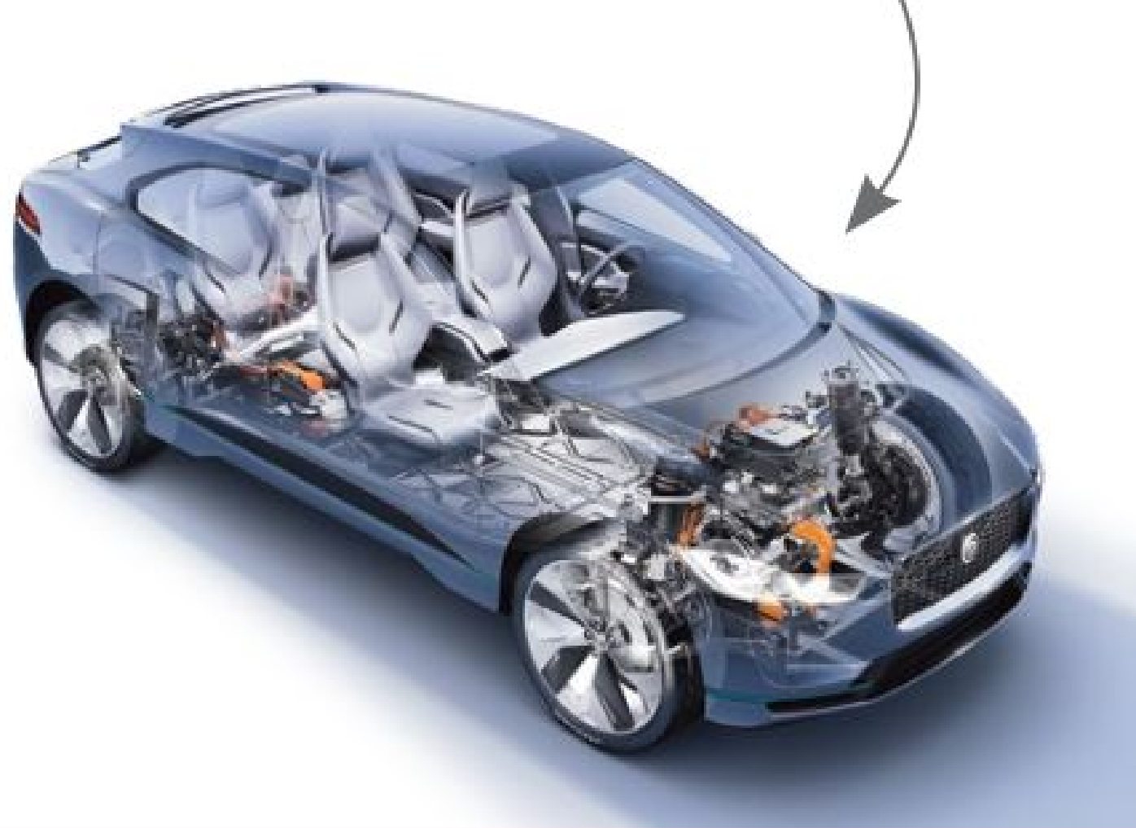


What lies beneath the Earth's surface?

How do bees make honey?

How does a single tree serve its own ecosystem?

How could humans live on Mars?



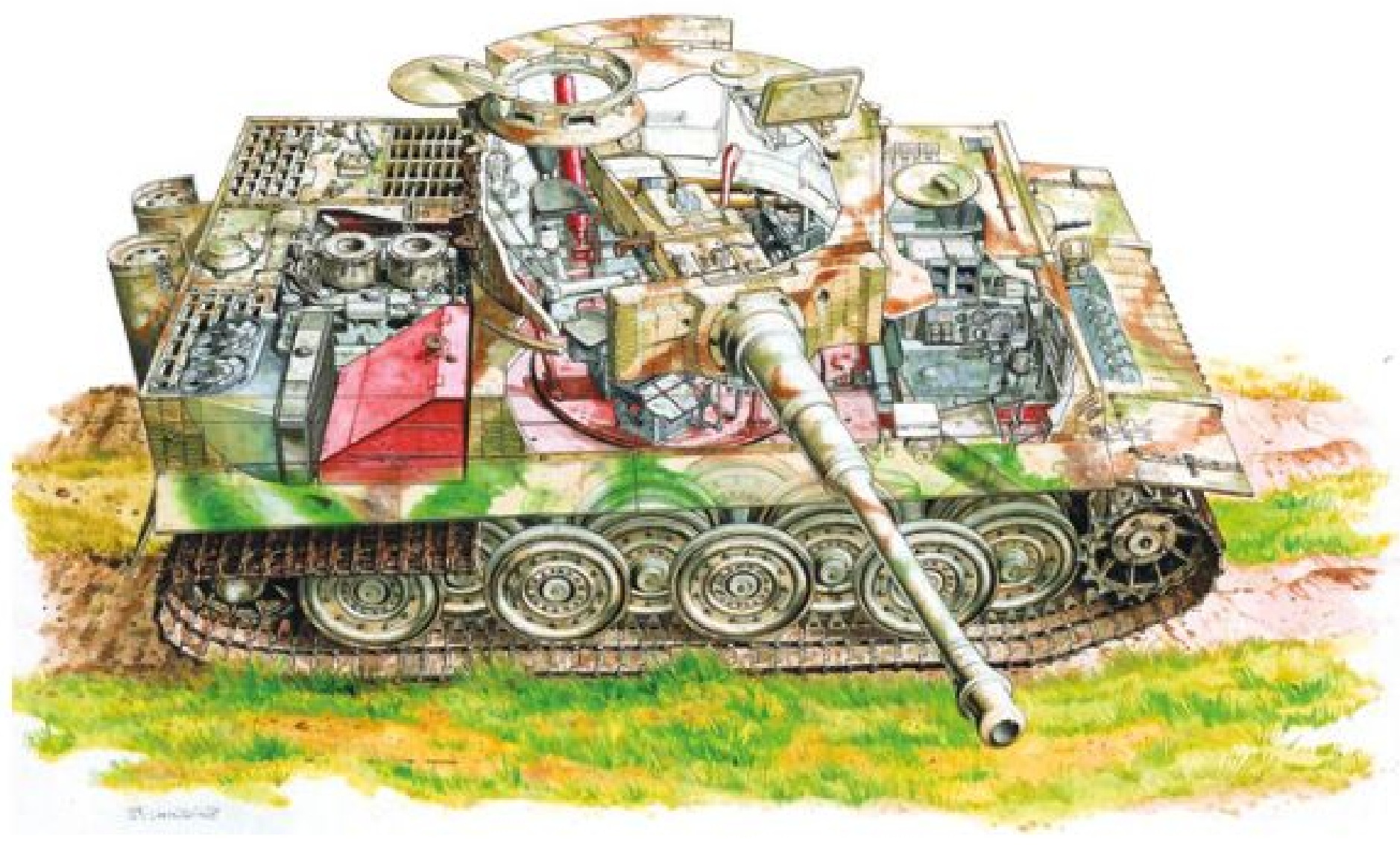
Inside Jaguar's first all-electric road car

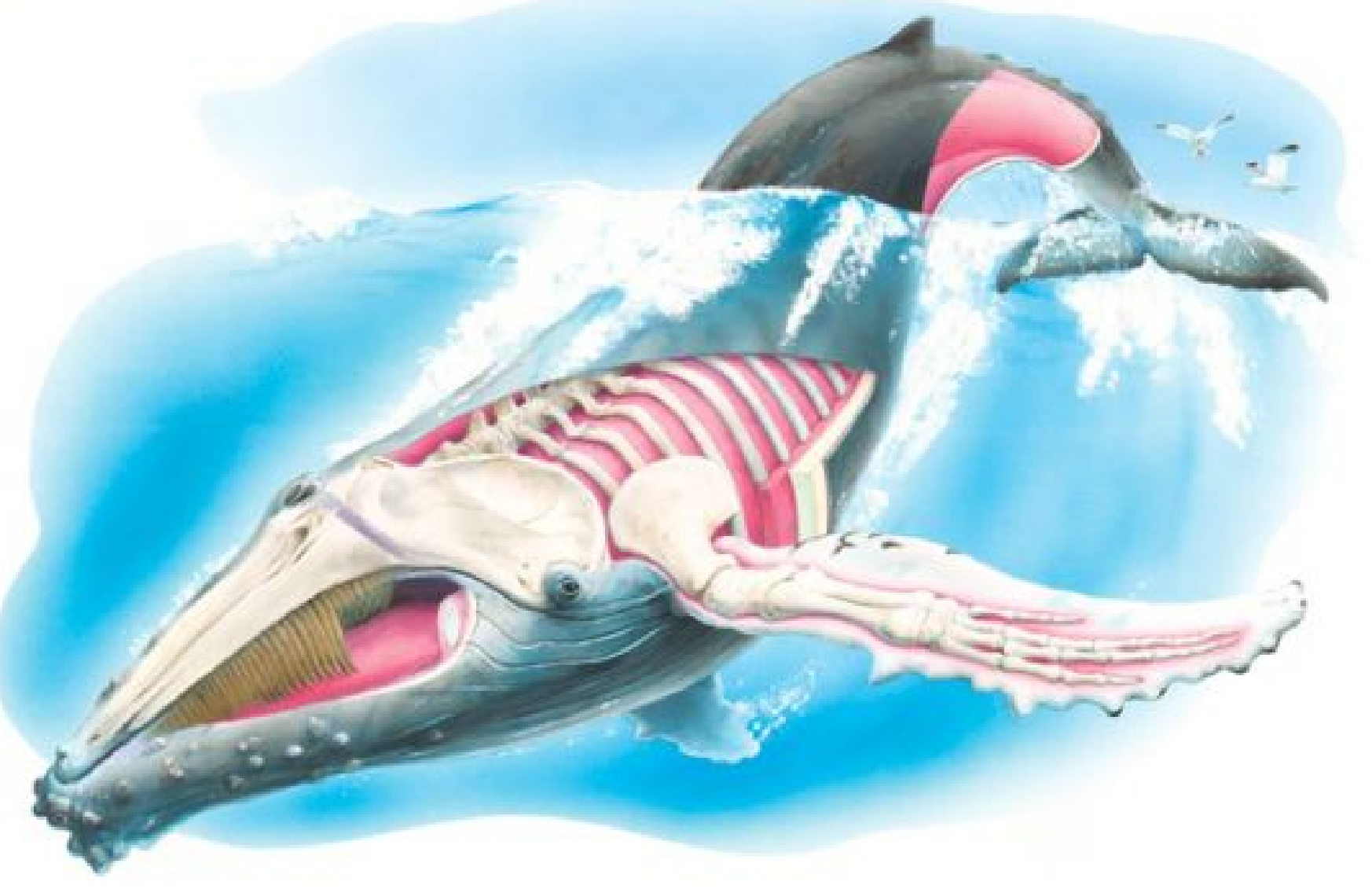
Digital Edition

FUTURE

FIRST EDITION

SCIENCE ENVIRONMENT TECH TRANSPORT HISTORY SPACE





WELCOME TO

HOW IT WORKS

AMAZING CUTAWAYS

In Amazing Cutaways, we delve deeper into the wonderful worlds of science, technology, transport, history, space and the environment with a selection of some of the best illustrations from the pages of **How It Works**. Get under the skin of the human body as we find out what happens to our food on a journey through the digestive system and discover how our immune system protects us from harm. Check out the habitats that will help humans live and thrive on Mars and learn how NASA's legendary Space Shuttle worked. Explore some of the wonders of the natural world, including how tigers hunt their prey and the importance of trees on the environment around them. Go inside the smart homes of the future and learn about the amazing tech that shapes our world. Take a look under the hood of the Humvee, a Red Arrow and superyachts. Discover how the dome of Florence Cathedral was constructed and examine how Notre-Dame will be rebuilt following 2019's devastating fire. And that's not all – read on for even more fantastic artwork and features.

This bookazine is printed on recycled paper. It's important that
we care about our planet and make a difference where we can,
for us and every generation that follows.

AMAZING CUTAWAYS

Future PLC Richmond House, 33 Richmond Hill,
Bournemouth, Dorset, BH2 6EZ

Bookazine Editorial
Editor **Dan Peel**
Senior Art Editor **Andy Downes**
Editorial Director **Jon White**

How It Works Editorial
Editor **Ben Biggs**
Designer **Duncan Crooks**

Cover images
DK Images, Thinkstock, Getty Images, Shutterstock, Adrian Mann, Nicholas Forder, The Art Agency/Barry Croucher, NASA, Alex Pang, Jaguar Land Rover

Photography
All copyrights and trademarks are recognised and respected

Advertising
Media packs are available on request
Commercial Director **Clare Dove**
clare.dove@futurenet.com

International
Head of Print Licensing **Rachel Shaw**
licensing@futurenet.com

Circulation
Head of Newstrade **Tim Mathers**

Production
Head of Production **Mark Constance**
Production Project Manager **Clare Scott**
Advertising Production Manager **Joanne Crosby**
Digital Editions Controller **Jason Hudson**
Production Managers **Keely Miller, Nola Cokely, Vivienne Calvert, Fran Twentyman**

Management
Chief Content Officer **Aaron Asadi**
Commercial Finance Director **Dan Jotcham**
Head of Art & Design **Greg Whitaker**

Printed by William Gibbons, 26 Planetary Road,
Willenhall, West Midlands, WV13 3XT

Distributed by Marketforce, 5 Churchill Place, Canary Wharf, London, E14 5HU
www.marketforce.co.uk Tel: 0203 787 9001

How It Works Book of Amazing Cutaways First Edition
© 2019 Future Publishing Limited

We are committed to only using magazine paper which is derived from responsibly managed, certified forestry and chlorine-free manufacture. The paper in this magazine was sourced and produced from sustainable managed forests, conforming to strict environmental and socioeconomic standards. The manufacturing paper mill and printer hold full FSC and PEFC certification and accreditation.

All contents © 2019 Future Publishing Limited or published under licence. All rights reserved. No part of this magazine may be used, stored, transmitted or reproduced in any way without the prior written permission of the publisher. Future Publishing Limited (company number 2008885) is registered in England and Wales. Registered office: Quay House, The Ambury, Bath BA1 1UA. All information contained in this publication is for information only and is, as far as we are aware, correct at the time of going to press. Future cannot accept any responsibility for errors or inaccuracies in such information. You are advised to contact manufacturers and retailers directly with regard to the price of products/services referred to in this publication. Apps and websites mentioned in this publication are not under our control. We are not responsible for their contents or any other changes or updates to them. This magazine is fully independent and not affiliated in any way with the companies mentioned herein.

FUTURE

Connectors.
Creators.
Experience
Makers.

Future plc is a public company quoted on the London Stock Exchange (symbol: FUTR)
www.futureplc.com

Chief executive **Zillah Byng-Thorne**
Non-executive chairman **Richard Huntingford**
Chief financial officer **Penny Ladkin-Brand**

Tel +44 (0)1225 442 244

Part of the
HOW IT WORKS
bookazine series

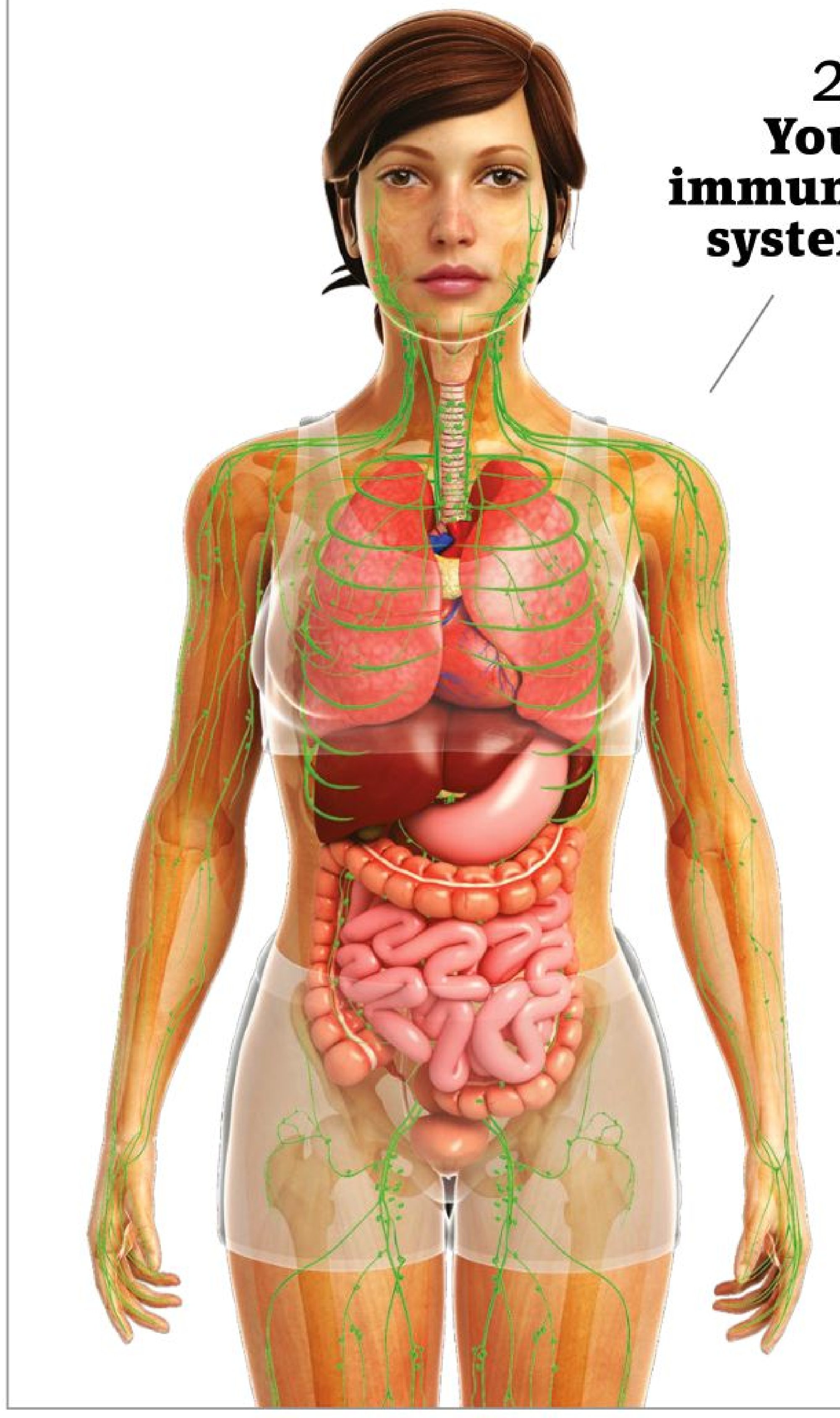
Widely Recycled

ipso. For press freedom with responsibility

CONTENTS

SCIENCE

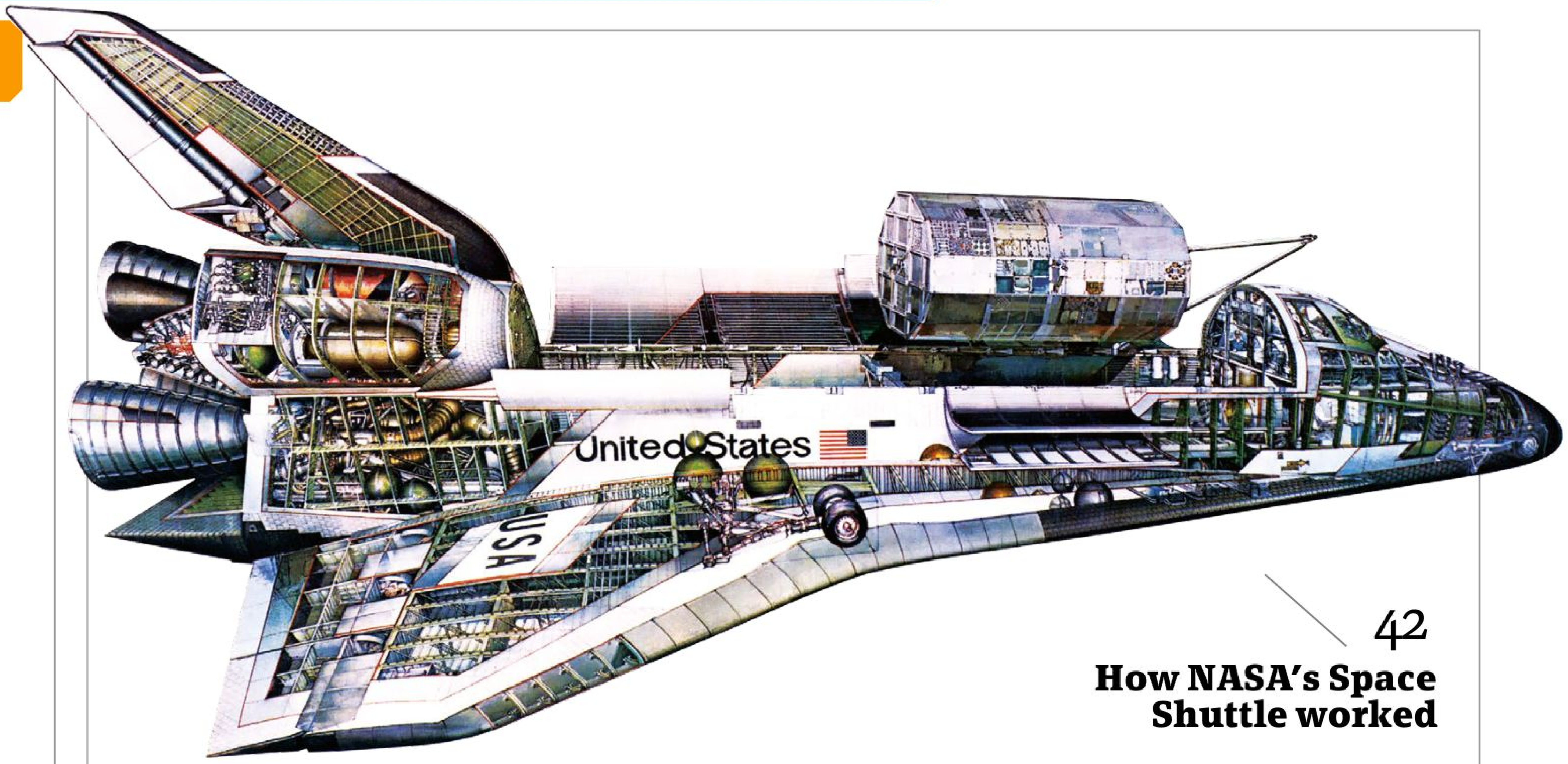
10 Journey through the human body's digestive system
20 What makes muscles strong?
22 How aerosols turn liquid into gas
24 The science of your skin
26 Your immune system
28 Inside your foot
29 Inside your hand
30 The science of Christmas dinner
32 Inside Chernobyl's Reactor 4



26 **Your immune system**

ENVIRONMENT

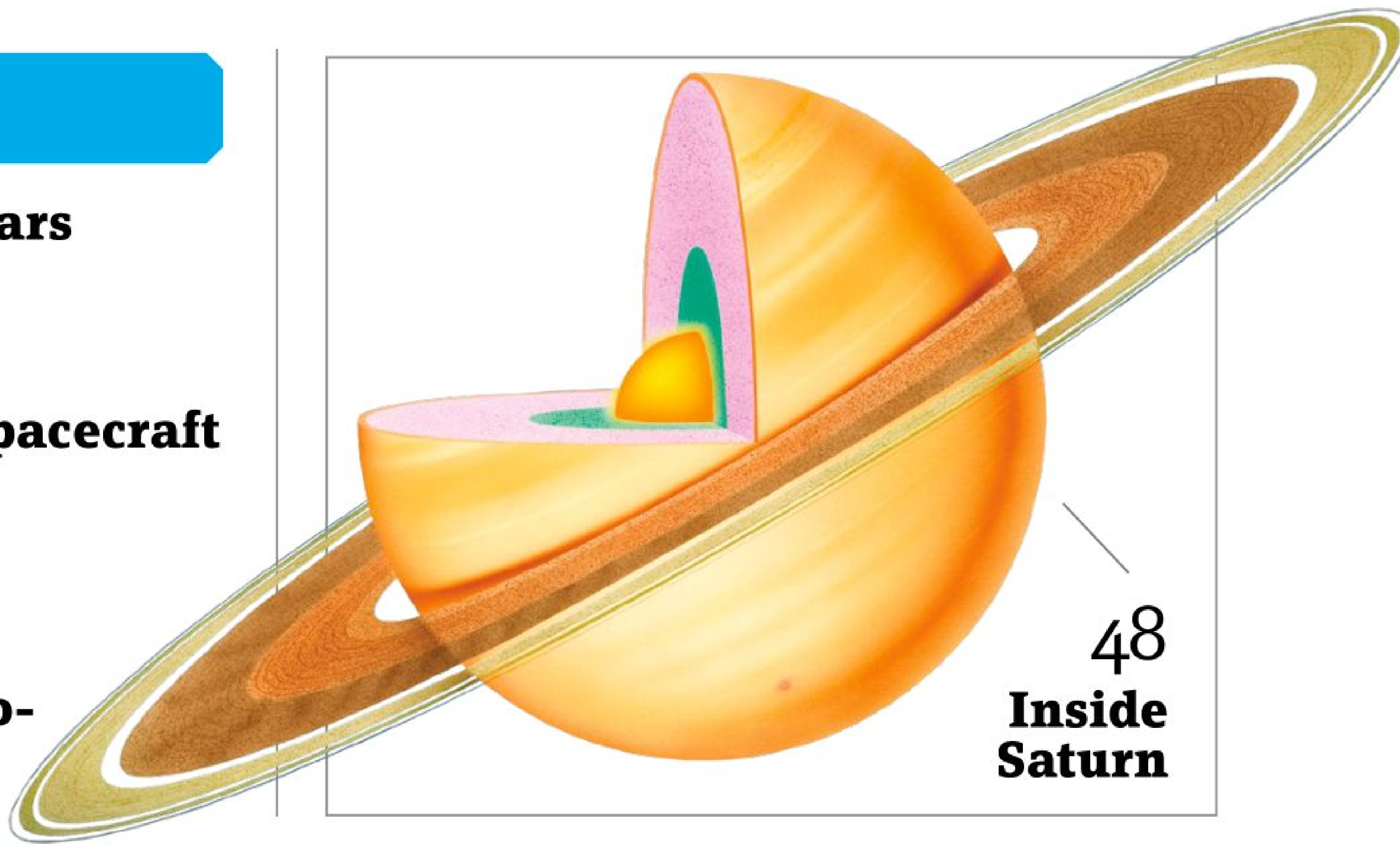
56 The Earth's structure
58 How tigers hunt
60 Trees of life
64 Anatomy of a volcano
66 What causes a landslide?
68 Humpback whales
70 How wells work
72 The honey factory
74 Shark anatomy



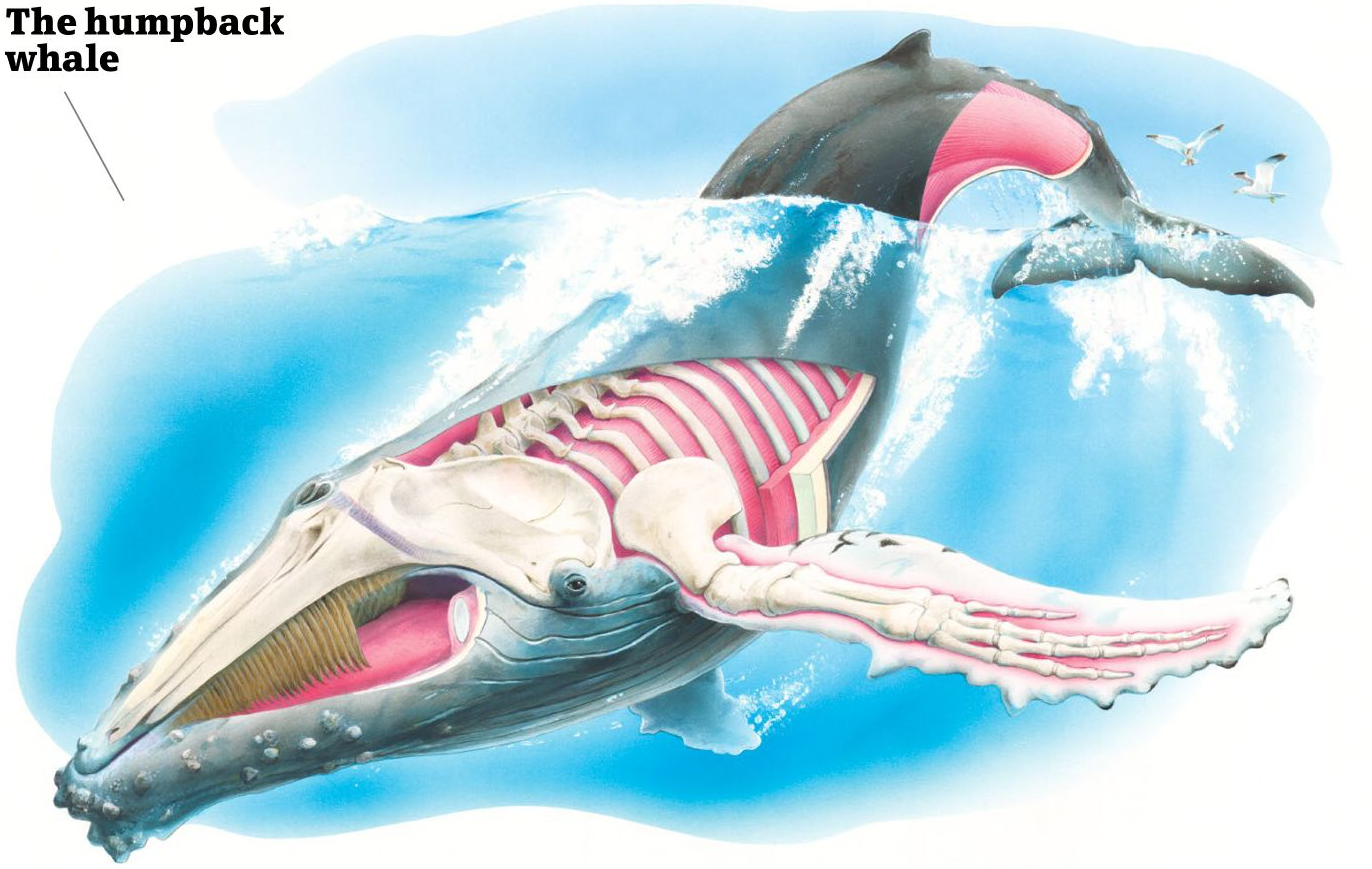
42 **How NASA's Space Shuttle worked**

SPACE

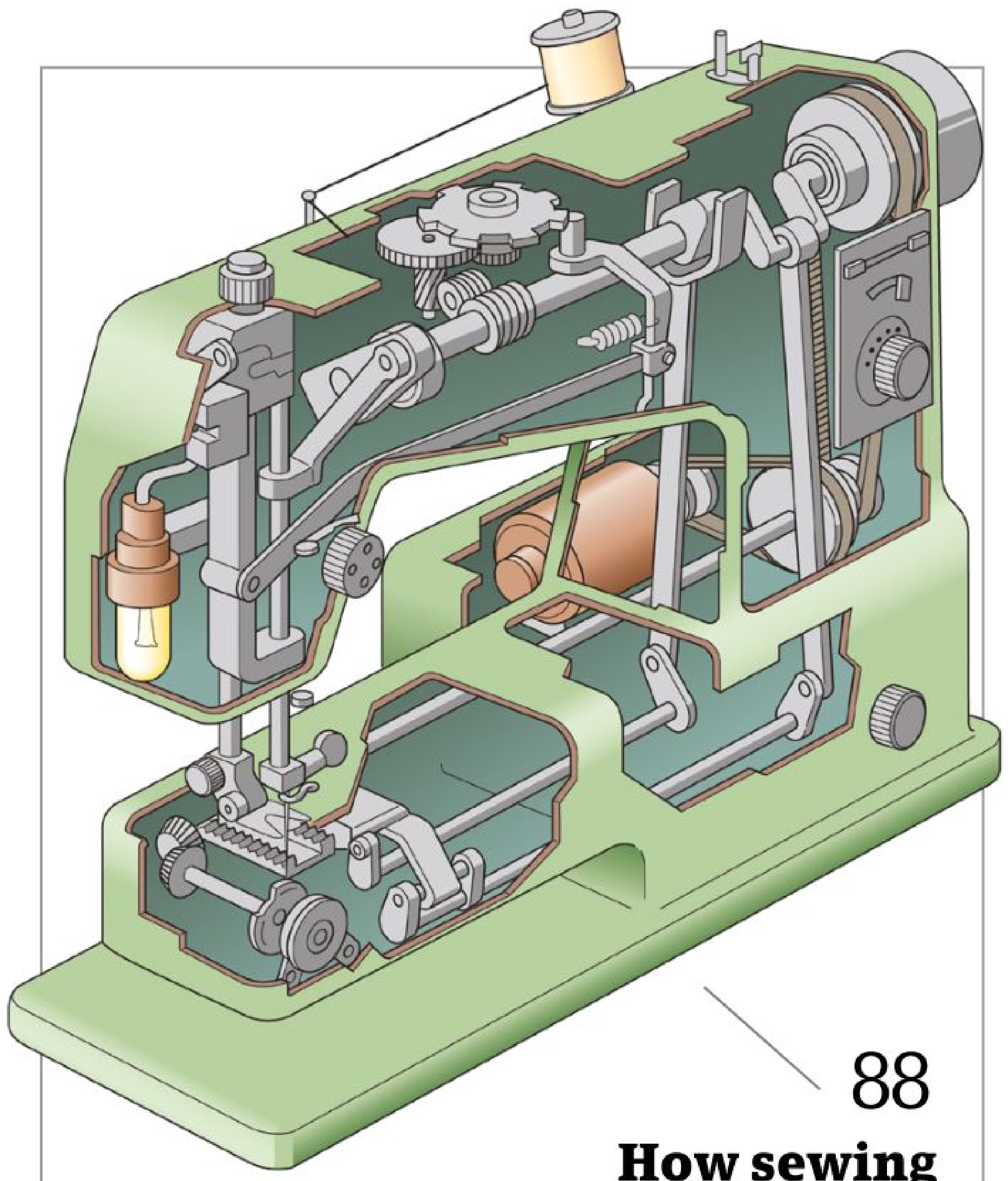
36 Human habitats on Mars
40 Inside the Sun
42 The Shuttle orbiter
44 Testing the limits of spacecraft
46 The Orion spacecraft
48 Saturn
50 Neutron stars
52 Anatomy of the Apollo-Saturn V Moon rocket



48 **Inside Saturn**



68 **The humpback whale**



88
How sewing machines work

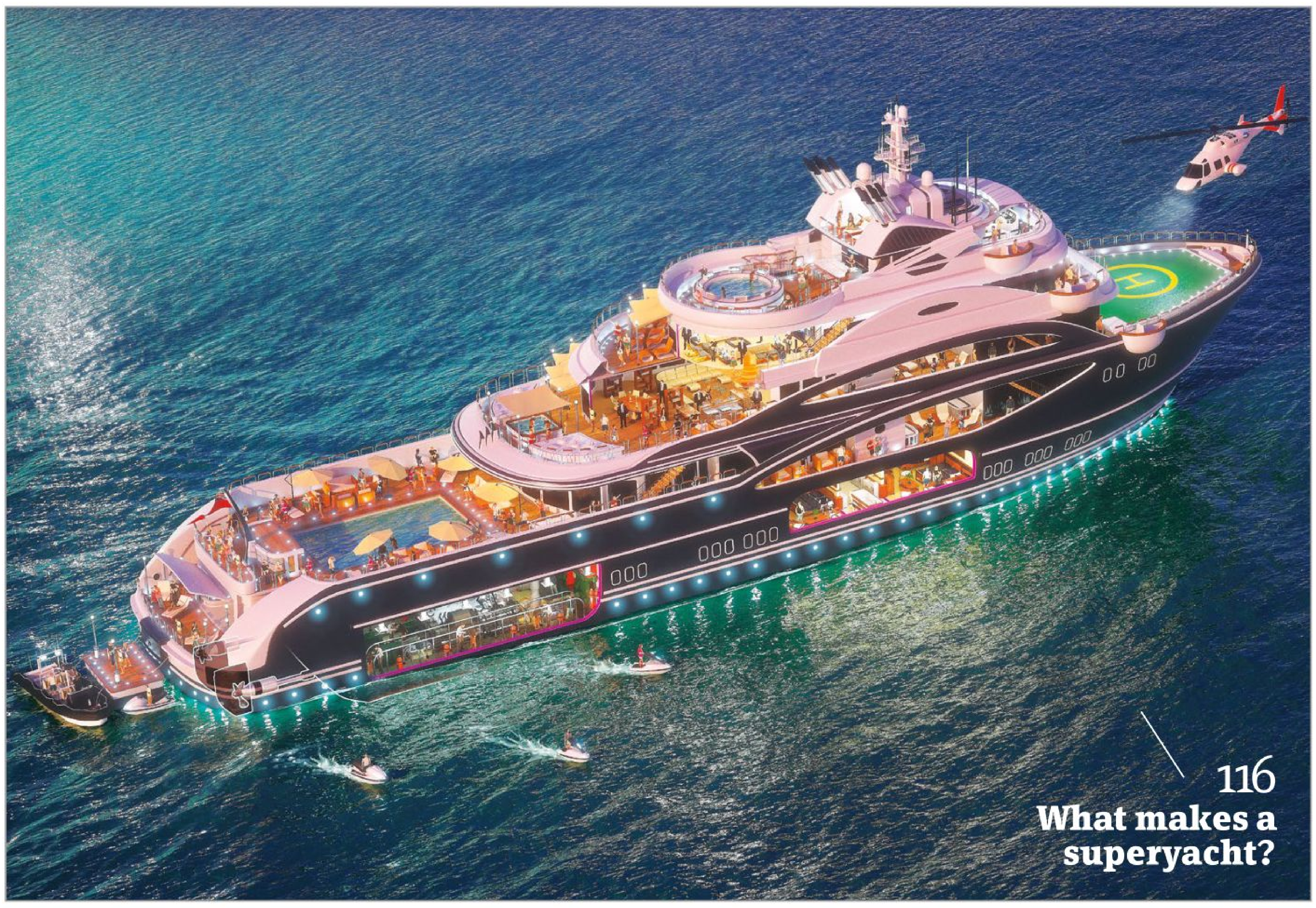
TECHNOLOGY

78 The Empire State Building
80 How does a CT scanner work?
82 Explore London's super-sewer
86 Welcome to your future smart home
88 How do sewing machines work?
89 Exploring a coal mine
90 Hoover Dam construction
92 Stand mixers

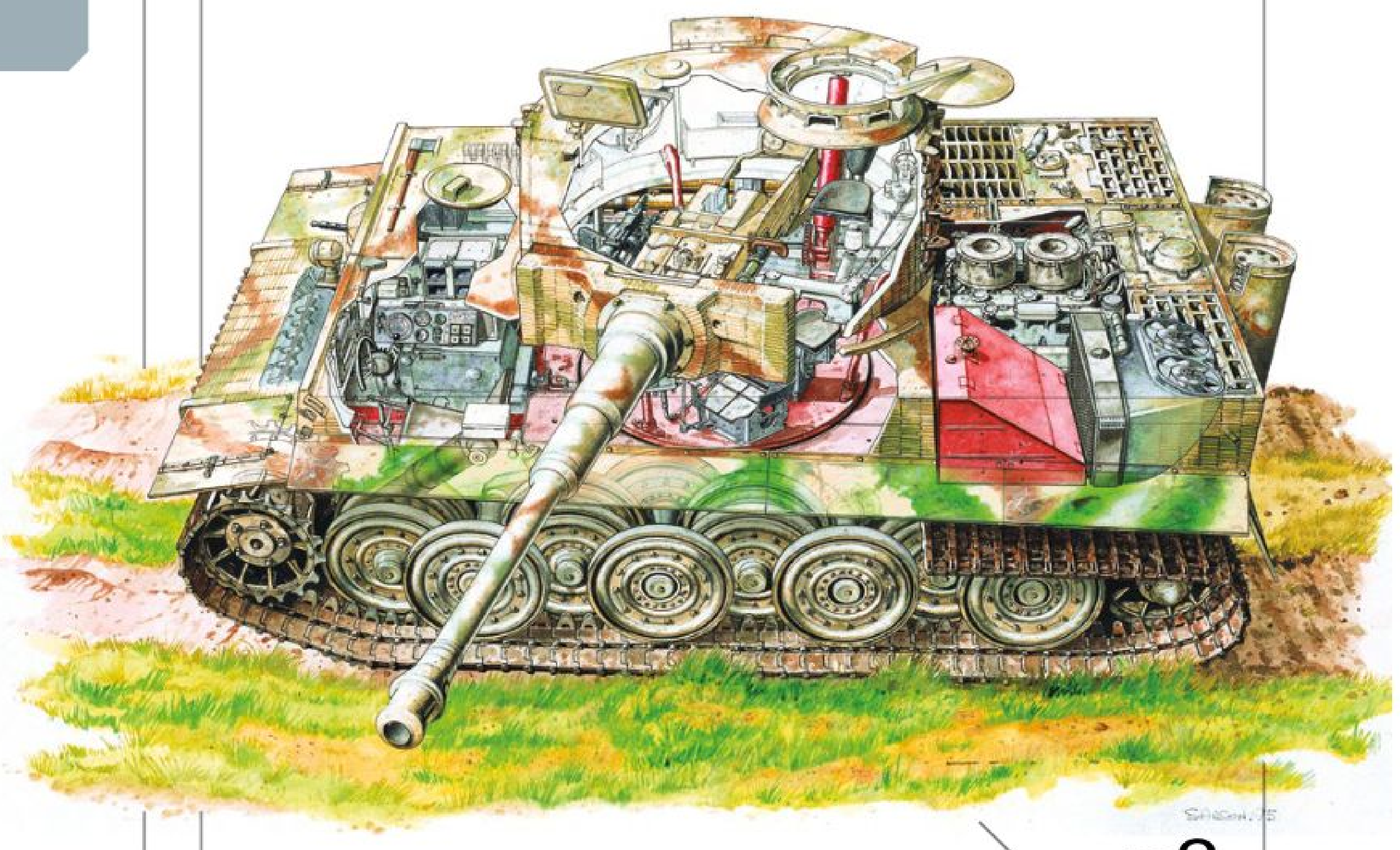
TRANSPORT

96 Inside a Red Arrow
100 Inside the I-PACE
102 Explore the RRS Sir David Attenborough
104 The Humvee
106 Snow groomers
108 How helicopters fly
110 How go-karts work
112 Abrams M1 Battletank
114 C-130 Hercules
116 What makes a superyacht?
118 F-22 Raptor vs F-35 Lightning II

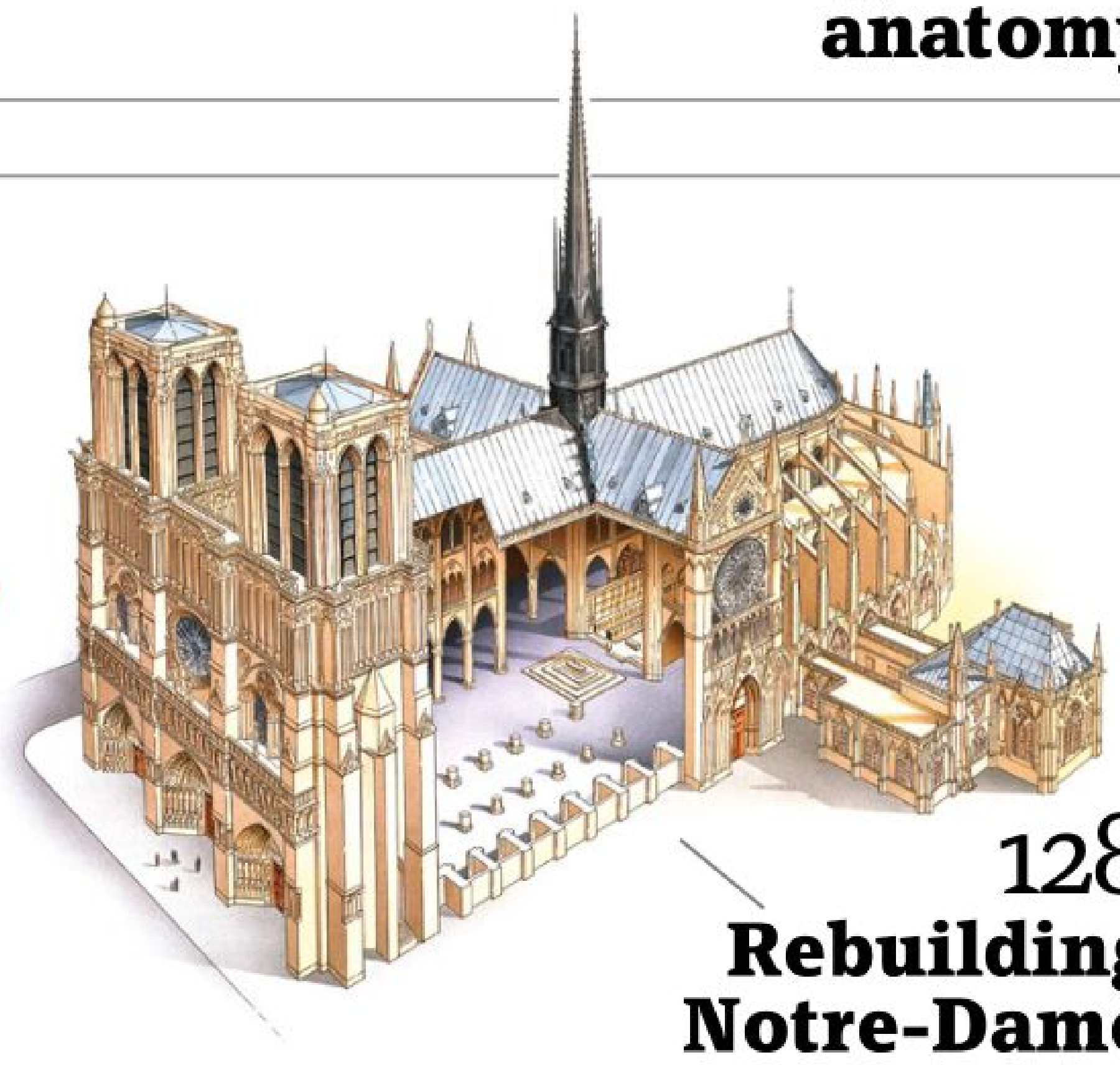
96
On board the Hawk



116
What makes a superyacht?



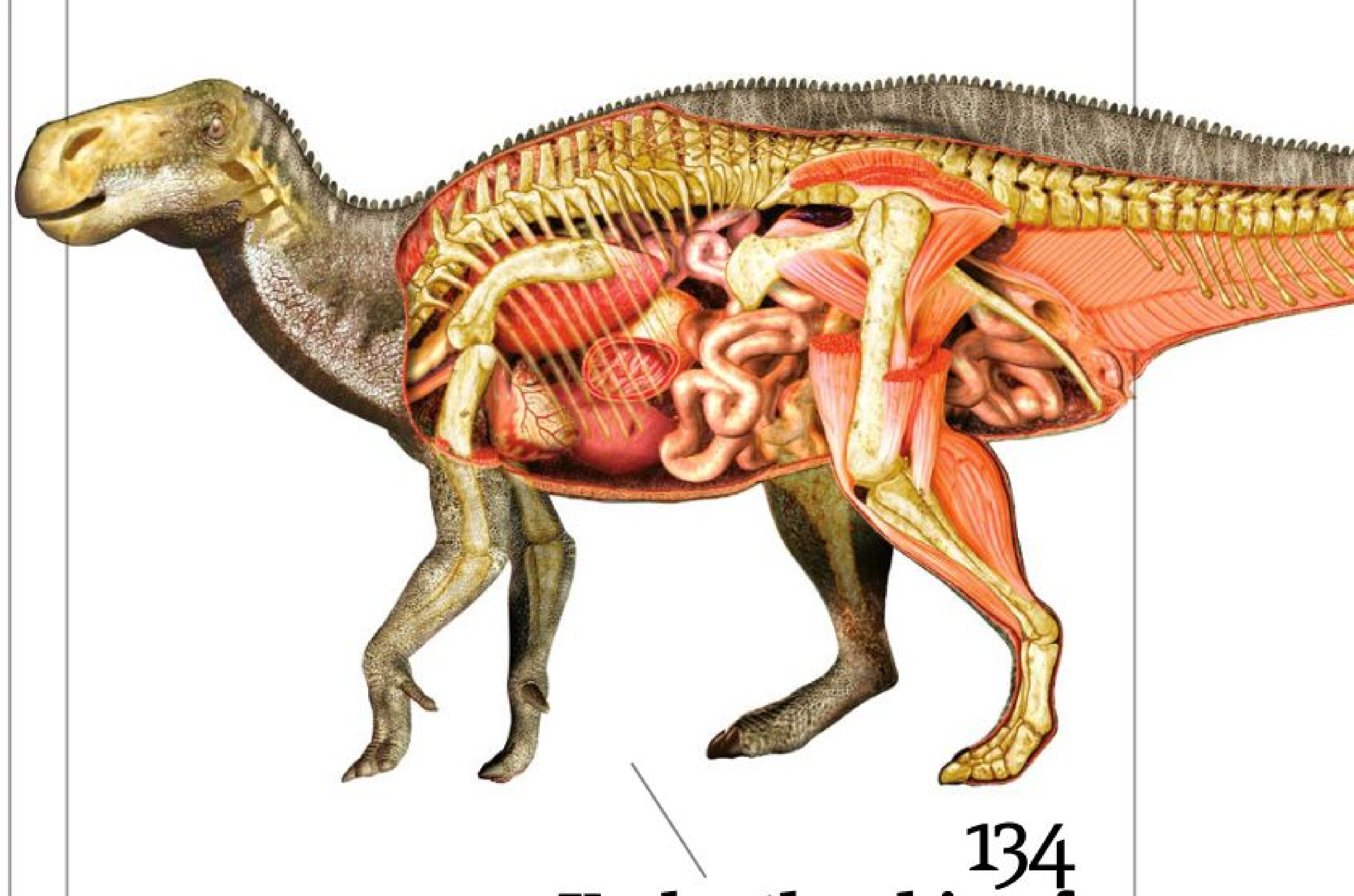
138
Tiger tank anatomy



128
Rebuilding Notre-Dame

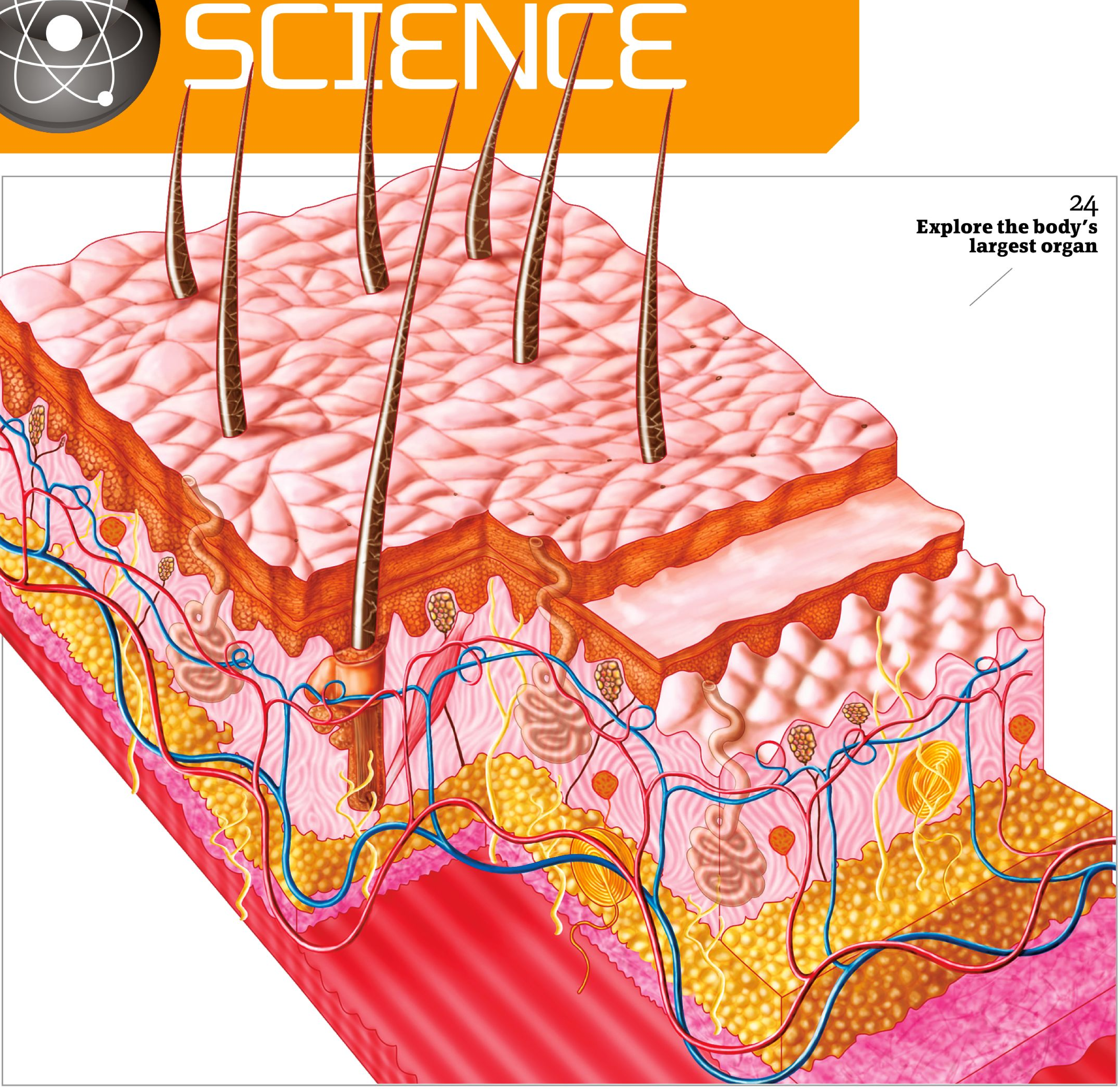
HISTORY

122 The sinking of Titanic
126 Supermarine Spitfire
128 Rebuilding Notre-Dame
130 Fossils
132 Inside the White House
134 The Iguanodon
136 Hampton Court Palace
138 Tiger tank anatomy
140 Florence Cathedral
142 Picking the Pope



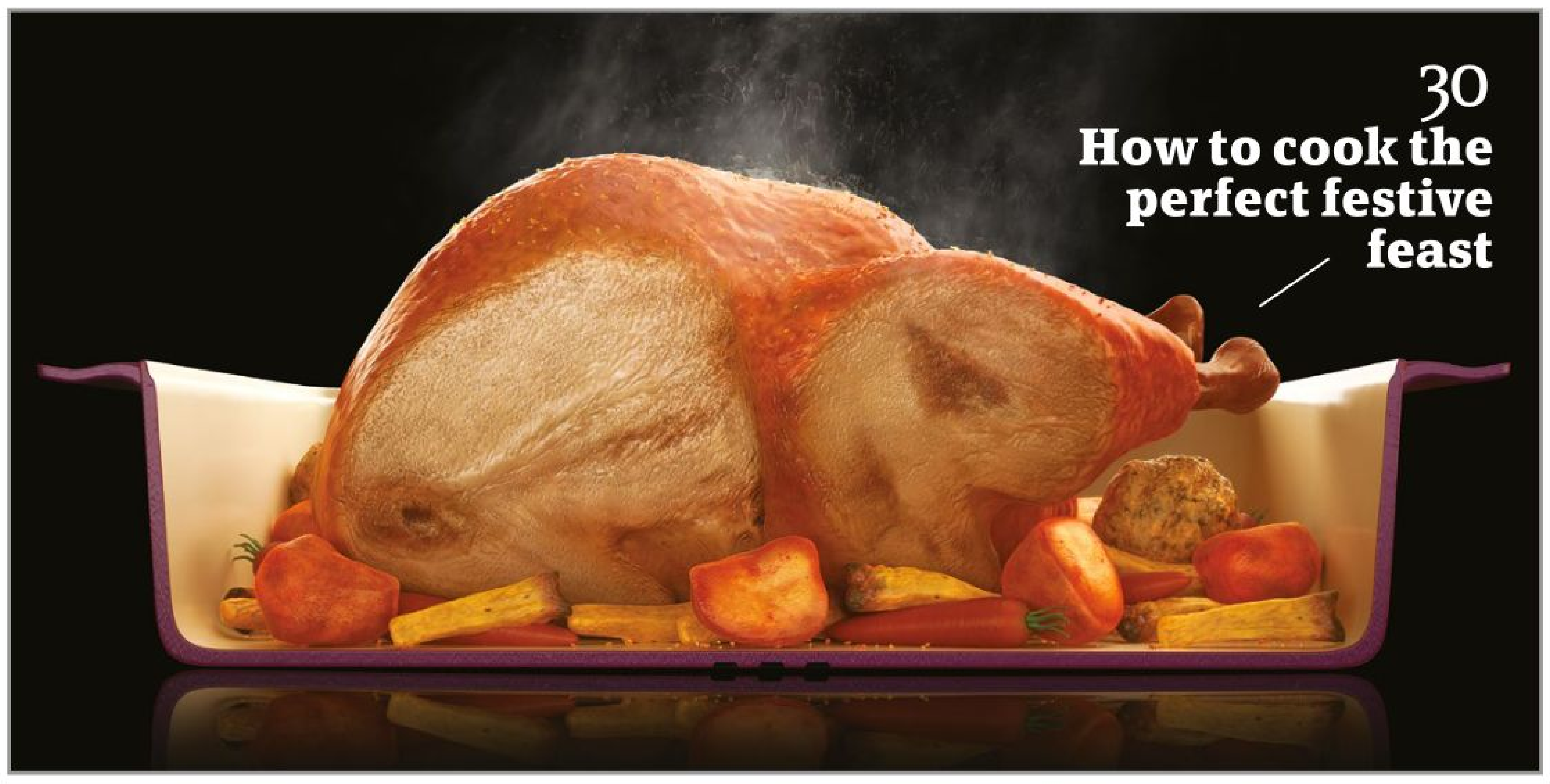
134
Under the skin of the Iguanodon

SCIENCE

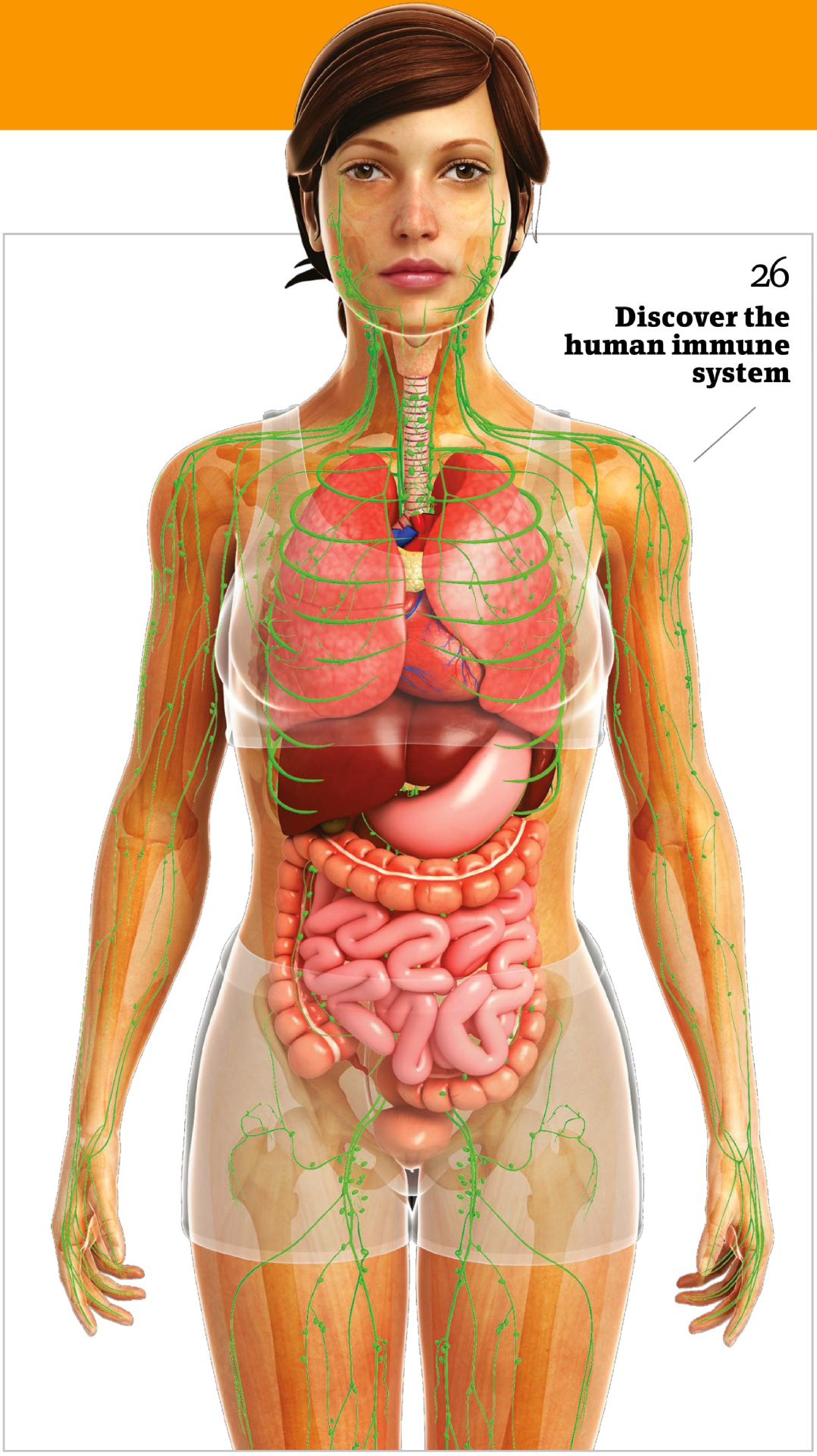


24
Explore the body's largest organ

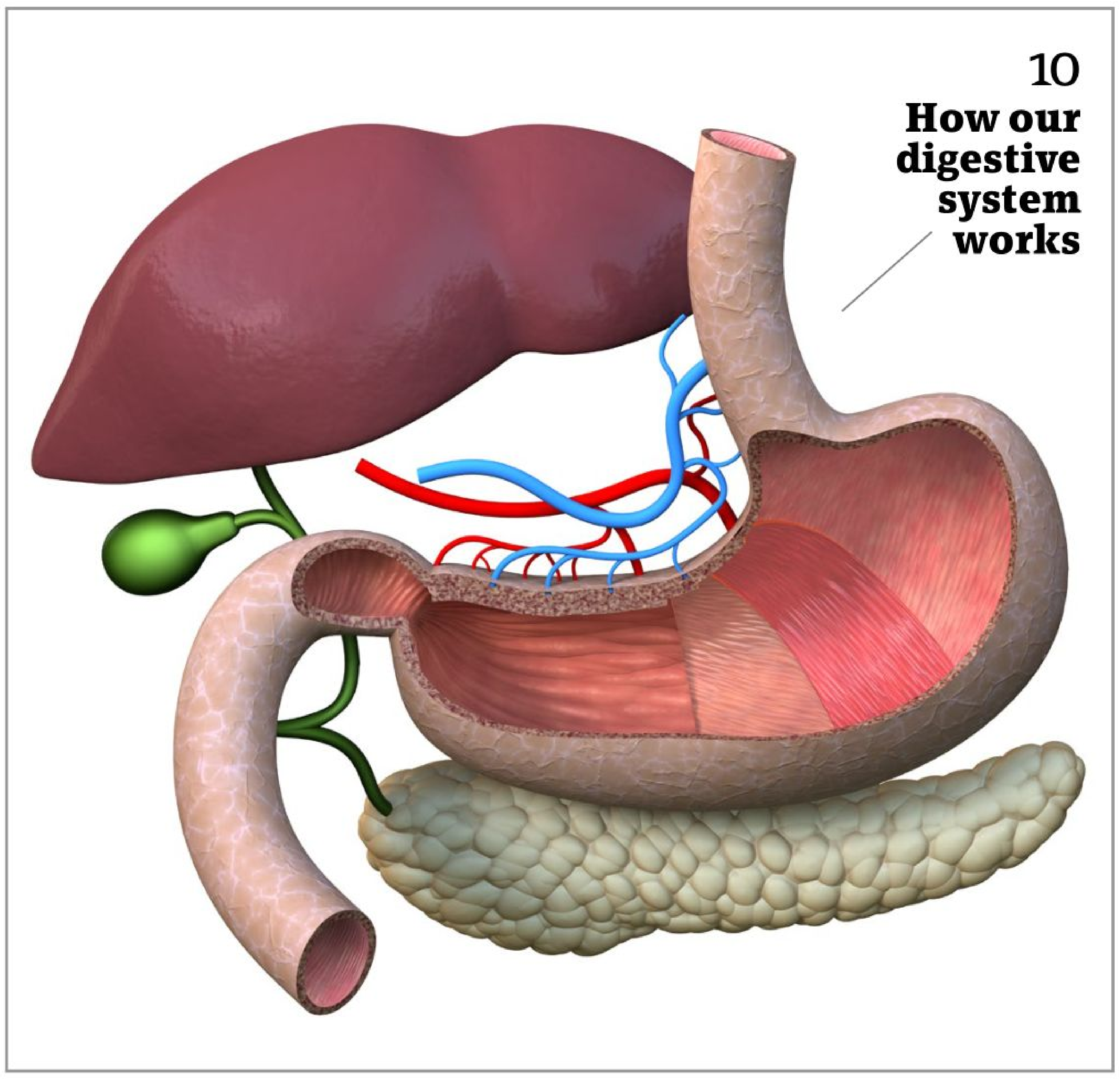
10 Journey through the human body's digestive system
20 What makes muscles strong?
22 How aerosols turn liquid into gas
24 The science of your skin
26 Your immune system
28 Inside your foot
29 Inside your hand
30 The science of Christmas dinner
32 Inside Chernobyl's Reactor 4



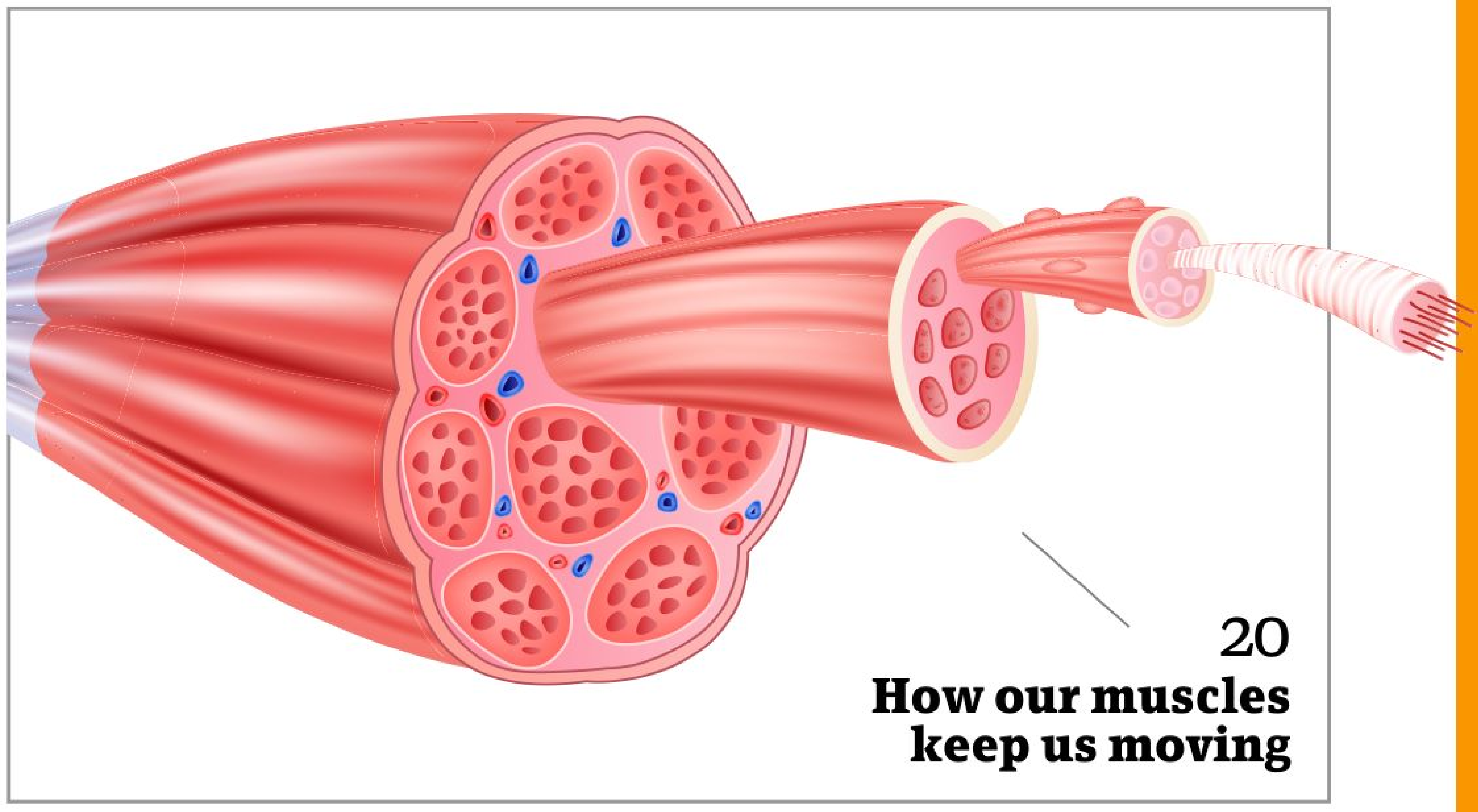
30
How to cook the perfect festive feast



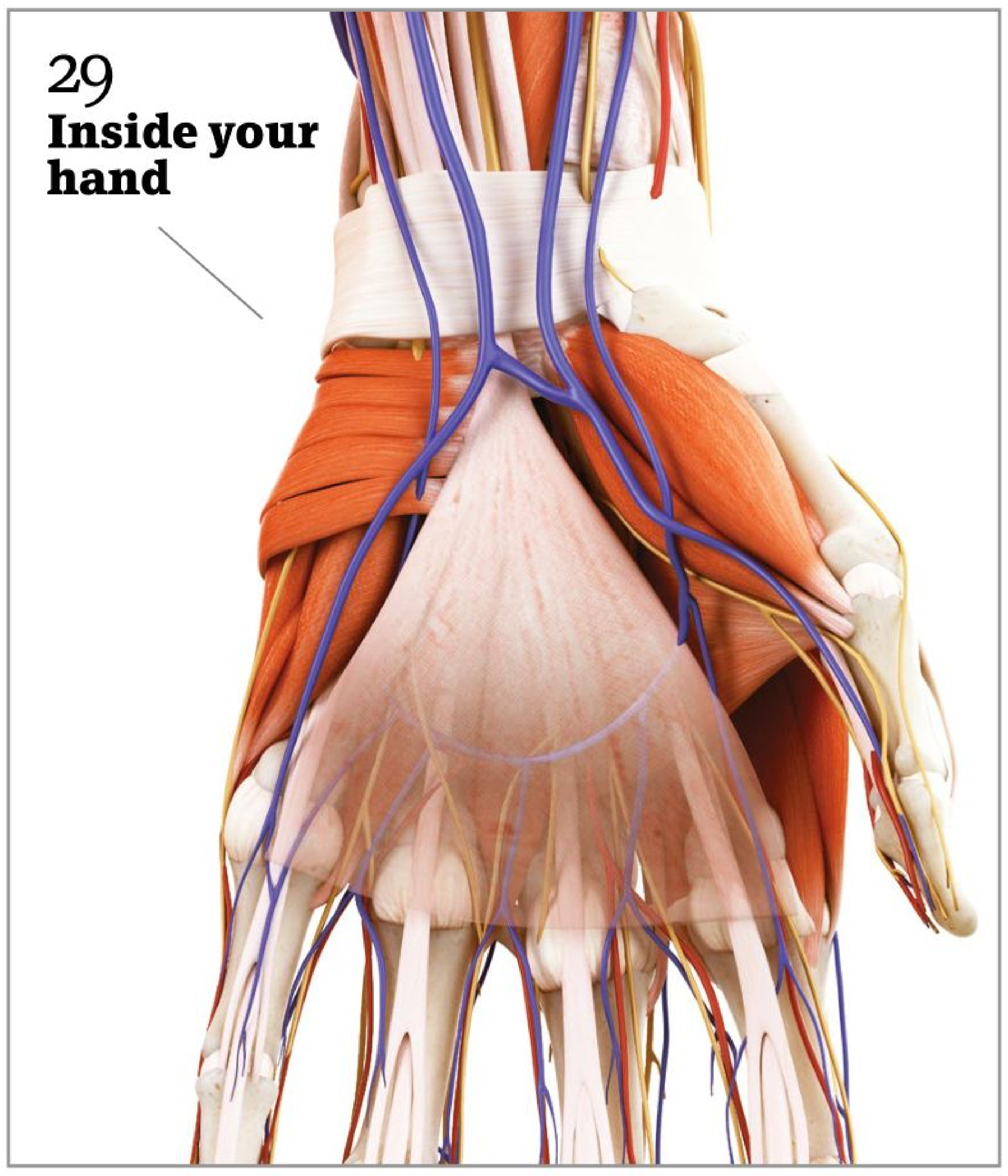
26
Discover the human immune system



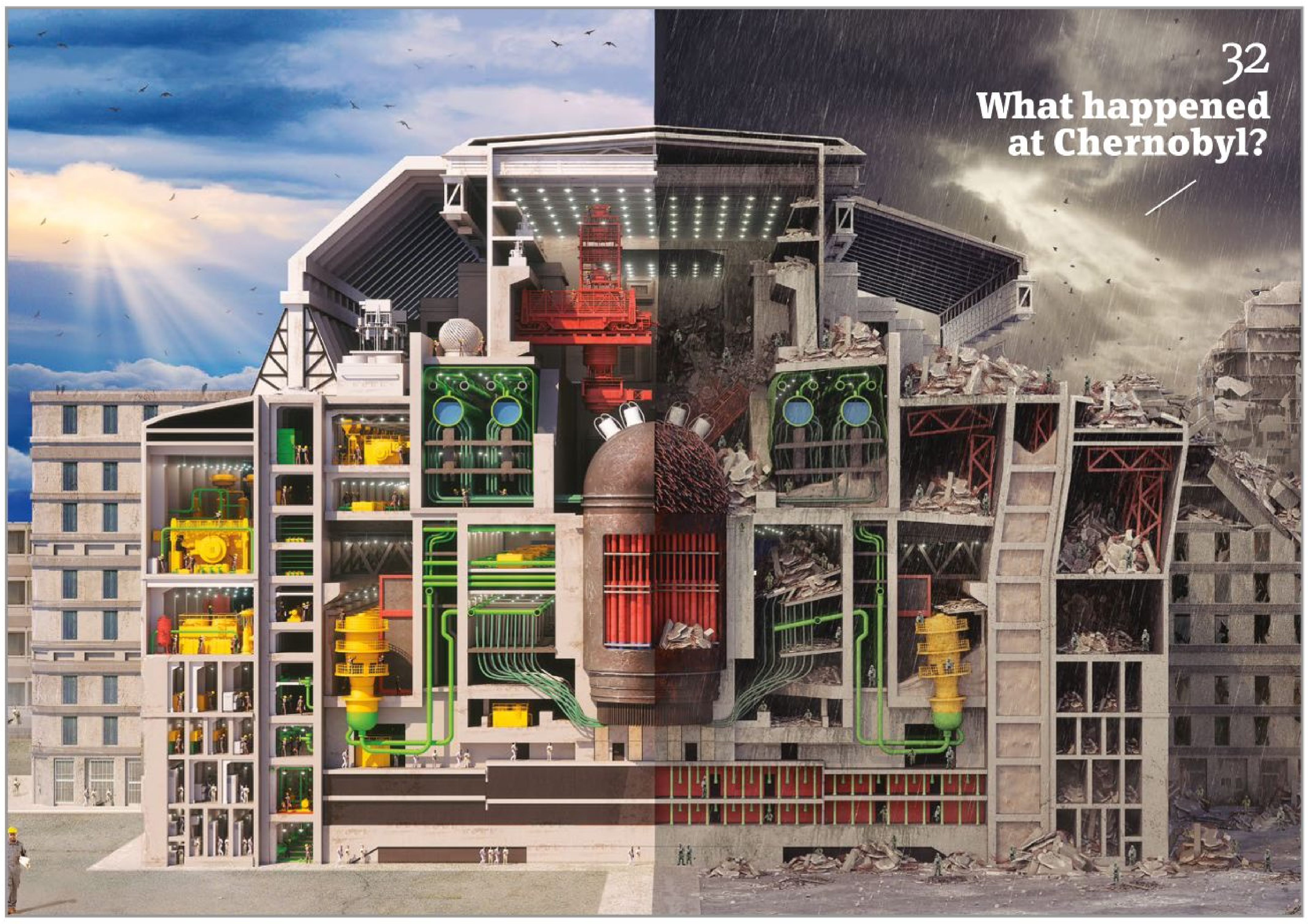
10
How our digestive system works



20
How our muscles keep us moving



29
Inside your hand



32
What happened at Chernobyl?

JOURNEY THROUGH the

From your mouth to your cells – how you are what you eat

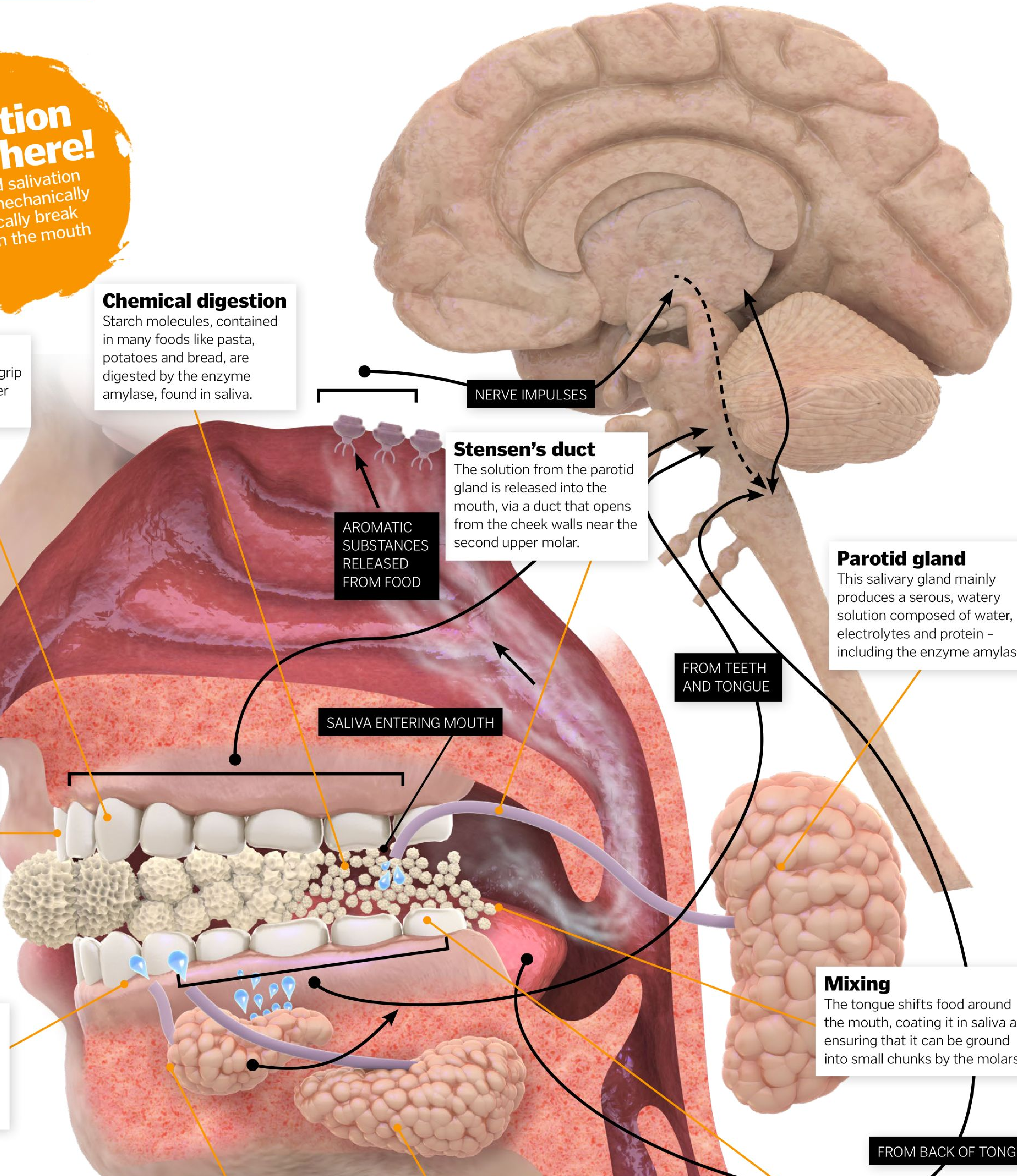
Words by **James Horton**

DID YOU KNOW? *A sword swallower tested one of the first endoscopes – cameras that look inside the GI tract*

HUMAN BODY'S
DIGESTIVE
SYSTEM

Digestion starts here!

Chewing and salivation combine to mechanically and chemically break down food in the mouth



Tearing
Sharp canine teeth grip and tear into tougher items of food.

Chemical digestion
Starch molecules, contained in many foods like pasta, potatoes and bread, are digested by the enzyme amylase, found in saliva.

Stensen's duct
The solution from the parotid gland is released into the mouth, via a duct that opens from the cheek walls near the second upper molar.

Parotid gland
This salivary gland mainly produces a serous, watery solution composed of water, electrolytes and protein – including the enzyme amylase.

Chopping
The narrow set of incisors sat at the front of the jaw specialise in slicing food into smaller chunks.

Mixing
The tongue shifts food around the mouth, coating it in saliva and ensuring that it can be ground into small chunks by the molars.

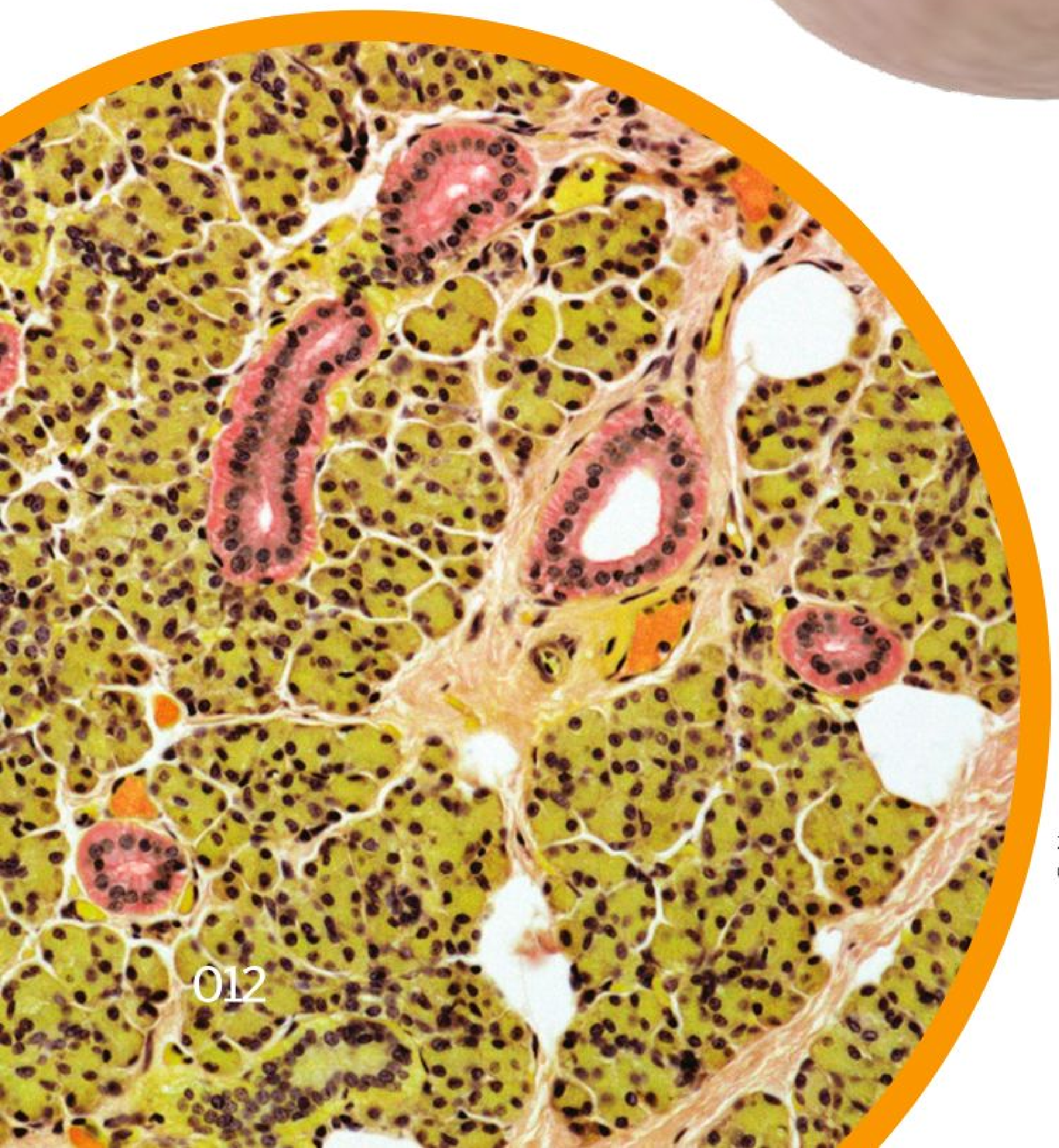
Wharton's duct
Solutions from the sub-salivary glands are secreted at the base of the tongue.

Sublingual gland
A thicker, mucosal form of saliva is predominantly produced here.

Submandibular gland
This set of glands creates a mixture of watery serous and thicker mucosal solutions.

Chomping
The large set of flat molars crush and grind food, providing a large part of the mechanical digestion that occurs in the mouth.

© Illustration by The Art Agency/Barry Croucher



The parotid gland is stuffed with serous acini – secretory units that produce isotonic, watery fluid

© Alamy

CHEWING, SALIVA & SWALLOWING

You are here

It took the evolution of life billions of years to arrive at the level of sophistication of the human being. Our bodies are home to trillions of cells all doing simple jobs on tiny scales, unaware that they're part of something so much greater than the sum of their parts. But as with any life, for their work to continue they need energy. And how do we fuel and continue to build this gargantuan machine? We drink and we eat.

Zooming out to you, we can see this quest for energy beginning as soon as you sense something delicious wafting in the air, spy a burger on a poster board or simply wait until your stomach gurgles at you unhappily. This desire for food is a summoning cry for billions of cells, collected into sophisticated organs, arranged into a stretch of tract that spans around nine metres in adults. From your mouth to your anus runs the gastrointestinal tract – the space where a banana, a yogurt or an apple pie are broken down into their component parts and either absorbed or eliminated. The absorbed molecules are then ready to be used as building blocks for maintaining, recycling and enhancing the world that is you.

Let's begin our journey with the summoning cry. A hormone known as ghrelin, which is produced mainly by the stomach, can be triggered when we so much as look at an image of a tasty meal or read the description of one on a menu. This sends a signal to our brain that increases our appetite, setting us on the path towards ingesting some precious energy.

The next part is the best – it's time to eat. Chewing and tasting food may be the moment of peak satisfaction for our brain, but the voyage for the food has only just begun.

> "This quest for energy begins as soon as you sense something delicious wafting in the air"

© Getty

Just looking at a tasty bit of food can be enough to trigger our appetite

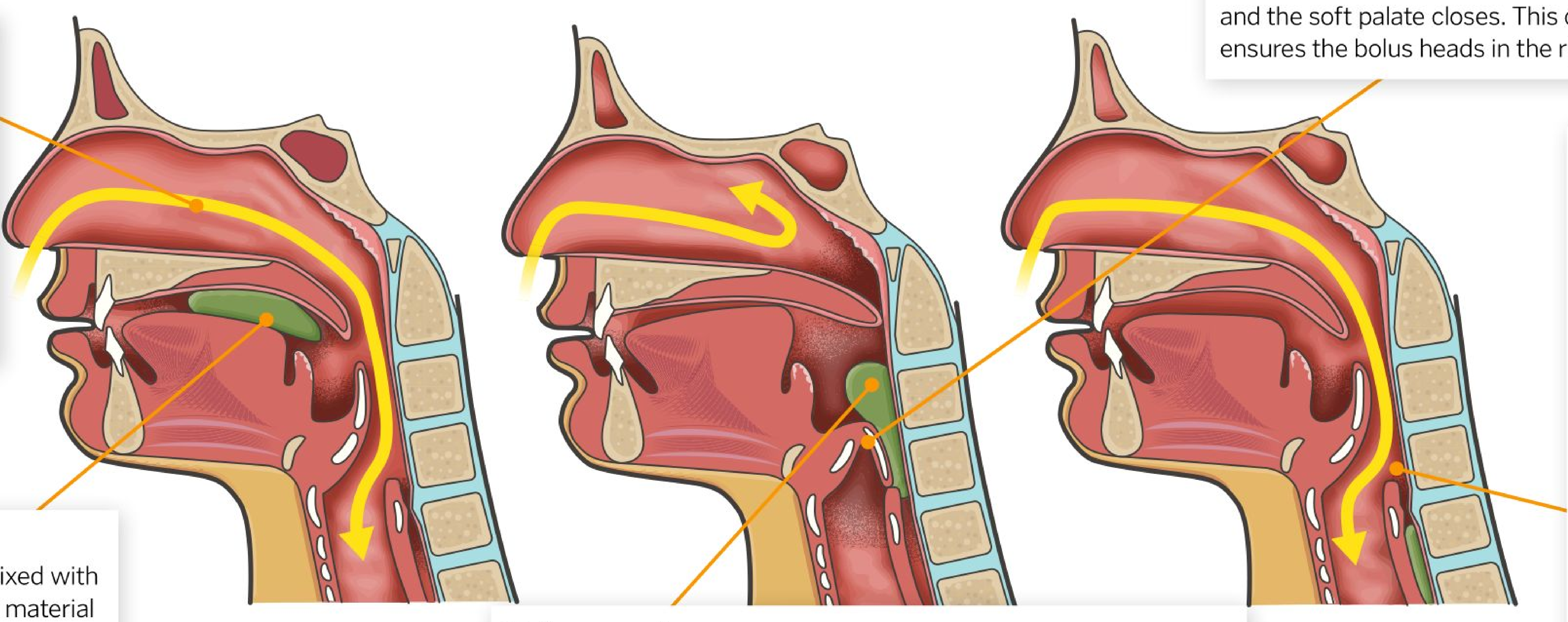
How the brain coordinates eating

The act of swallowing is one of the most delicate and complex processes performed by the human body, even though we rarely offer it a second thought. Like many crucial processes, much of swallowing is an involuntary action. This ensures that lubricated food is moved from our mouth to our stomach without getting stuck, coming out of our nose or blocking our windpipe.

The key control centre for swallowing is the brain stem, home of the medulla oblongata. This network is connected to a collection of cranial nerves that perform important functions, including sensing and controlling chewing, tasting, salivation and swallowing. The cranial nerves report the location and texture of the food bolus to the brain stem as it moves from the mouth to the pharynx to the oesophagus, triggering muscle contractions along the way.

The essential sequence of swallowing

How your body transports the food safely down your throat



No entry
At this stage the airways are open and the upper oesophageal sphincter – a ring of muscle that acts as a gateway to the oesophagus – is firmly shut.

Away we go
Chewed food that's mixed with saliva forms a lump of material known as a food bolus. The act of swallowing begins as the tongue pushes the food bolus towards the throat.

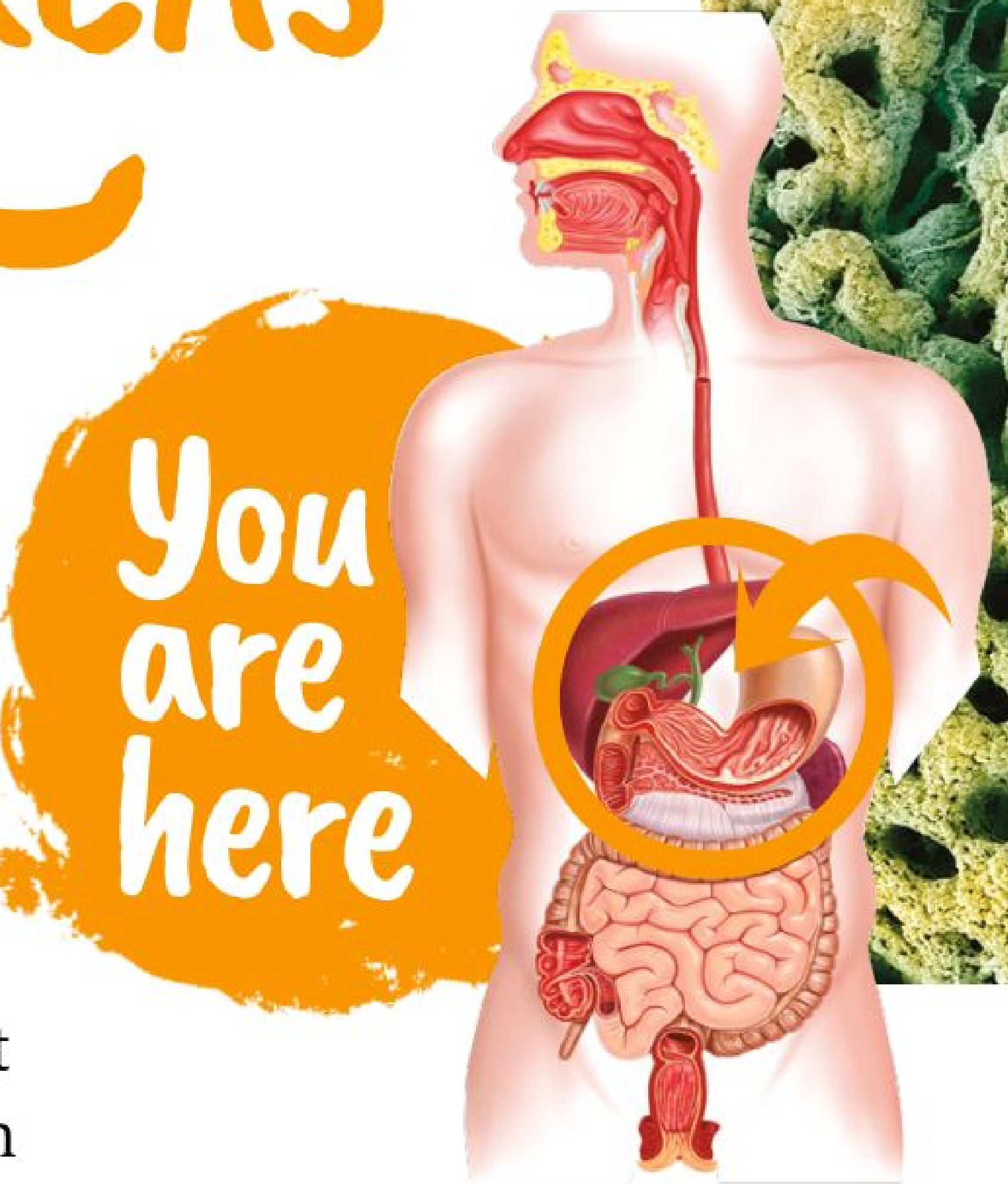
Triggered response
The arrival of the food bolus initiates a response known as deglutition. This involves a synchronised series of contractions of head and neck muscles to squeeze food into the oesophagus.

This way, please
As the food bolus is pushed towards the oesophagus, the upper oesophageal sphincter opens and the soft palate closes. This obstructs airflow but ensures the bolus heads in the right direction.

No return ticket
As soon as the food bolus has cleared the array of sensory receptors that coat the pharynx, the upper oesophageal sphincter clamps shut and the soft palate relaxes. Sequential muscular contractions continue in the oesophagus, pushing the bolus on and towards the stomach.

© Illustration by The Art Agency/Nick Sellers

STOMACH, DUODENUM, BILE DUCT & PANCREAS



© Getty

Human stomach lining is highly regenerative and can renew itself once every week

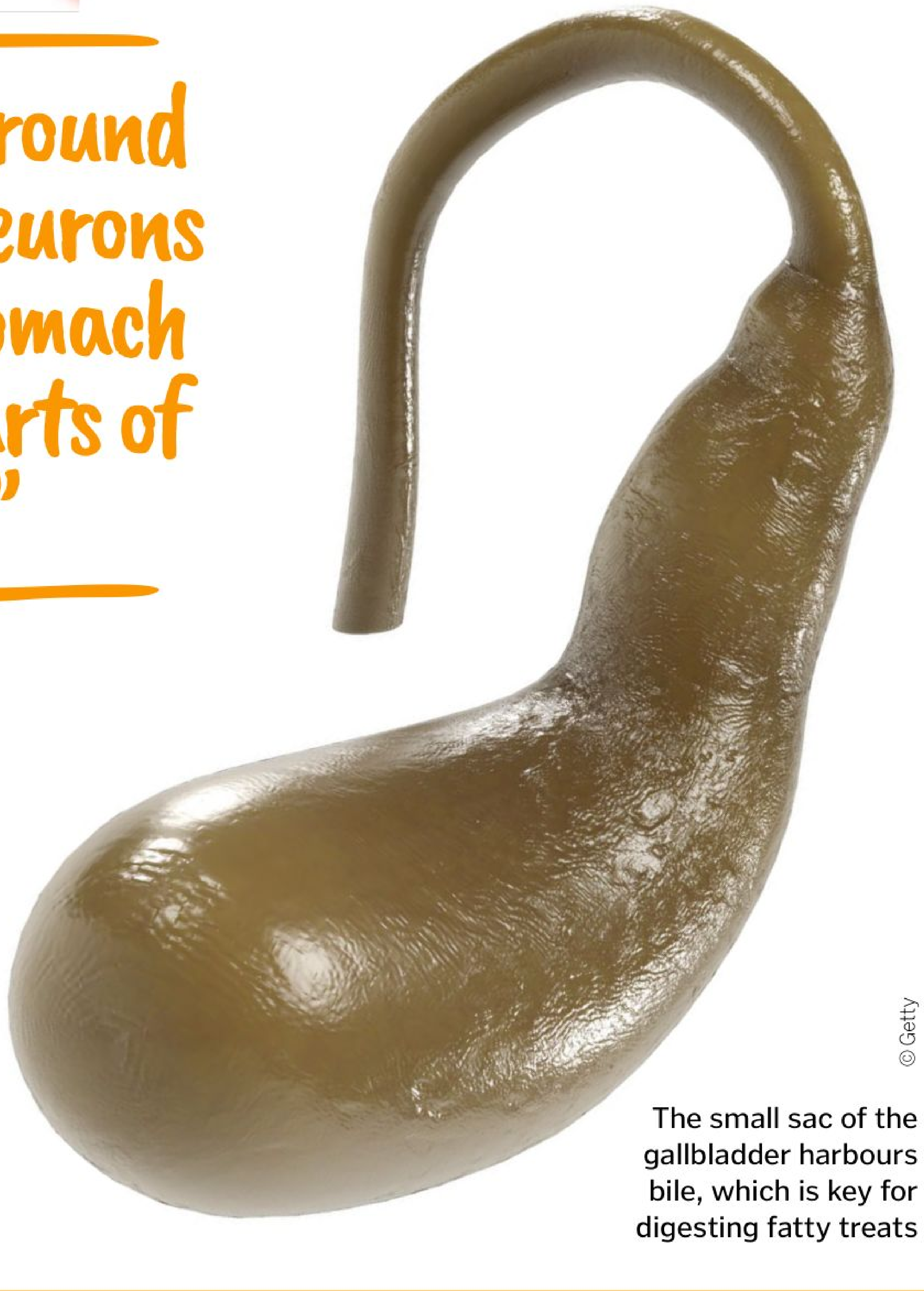
The period after we've just finished a meal is a crucial time for digestion. The recently arrived food bolus has already been partially digested in the mouth, but next comes exposure to an onslaught of digestive enzymes that will prepare the food's molecules for absorption in the intestines. The bolus first arrives through the pyloric sphincter into the stomach – a hostile alien environment where molecules are continuously secreted from the walls and activated by the pool of gastric acid that fills the chamber.

Alongside the stomach, a collection of other organs are busily producing and secreting their own cocktail of digestive enzymes. These will unite with the partially digested food in the duodenum, the organ that follows the stomach.

The stomach is a fascinating organ because one of its main jobs is storing and slowly releasing food into the small intestine. Without this limiting point, food would rapidly travel through the digestive tract, and we'd miss out on a huge amount of precious nutrients simply because our intestines wouldn't have time to absorb them. But the stomach is able to stretch and hold onto food for hours, methodically churning the material and setting upon it with its powerful stomach acid.

By the time the converted food leaves the lower chamber of the stomach and greets the awaiting digestive enzymes secreted by the neighbouring organs, it has been thoroughly prepared for its next step. It's nearly time for the food to become a part of you.

> "There are around 100 million neurons lining the stomach and other parts of the gut"


© Getty

The small sac of the gallbladder harbours bile, which is key for digesting fatty treats

THE MANY POWERS OF STOMACH ACID

1 **Bacteria killer**
The highly acidic environment is harmful to most microorganisms, including pathogenic bacteria.

2 **Pepsin switch**
Hydrochloric acid in the gastric juices converts pepsinogen, which is secreted from the stomach's walls, into protein-digesting pepsin.

3 **Protein unraveller**
Available pepsin in the acid breaks down protein structure, cutting the molecule into smaller chains of amino acids.

4 **Vitamin absorption**
Gastric acid helps stimulate the secretion of a glycoprotein known as intrinsic factor into the stomach, which will later bind to vitamin B12 in the small intestine.

5 **Bile delivery**
The presence of stomach acid in the small intestine helps to stimulate the release of fat-digesting bile.

6 **Blocks acid reflux**
The acidity of gastric juices helps to trigger the contraction of the lower oesophageal sphincter, helping to keep harmful acid away from the unprotected tubing.

7 **Aiding migration**
The pressure from the volume of stomach acid helps to open the pyloric sphincter briefly, transferring chyme and acid into the small intestine.

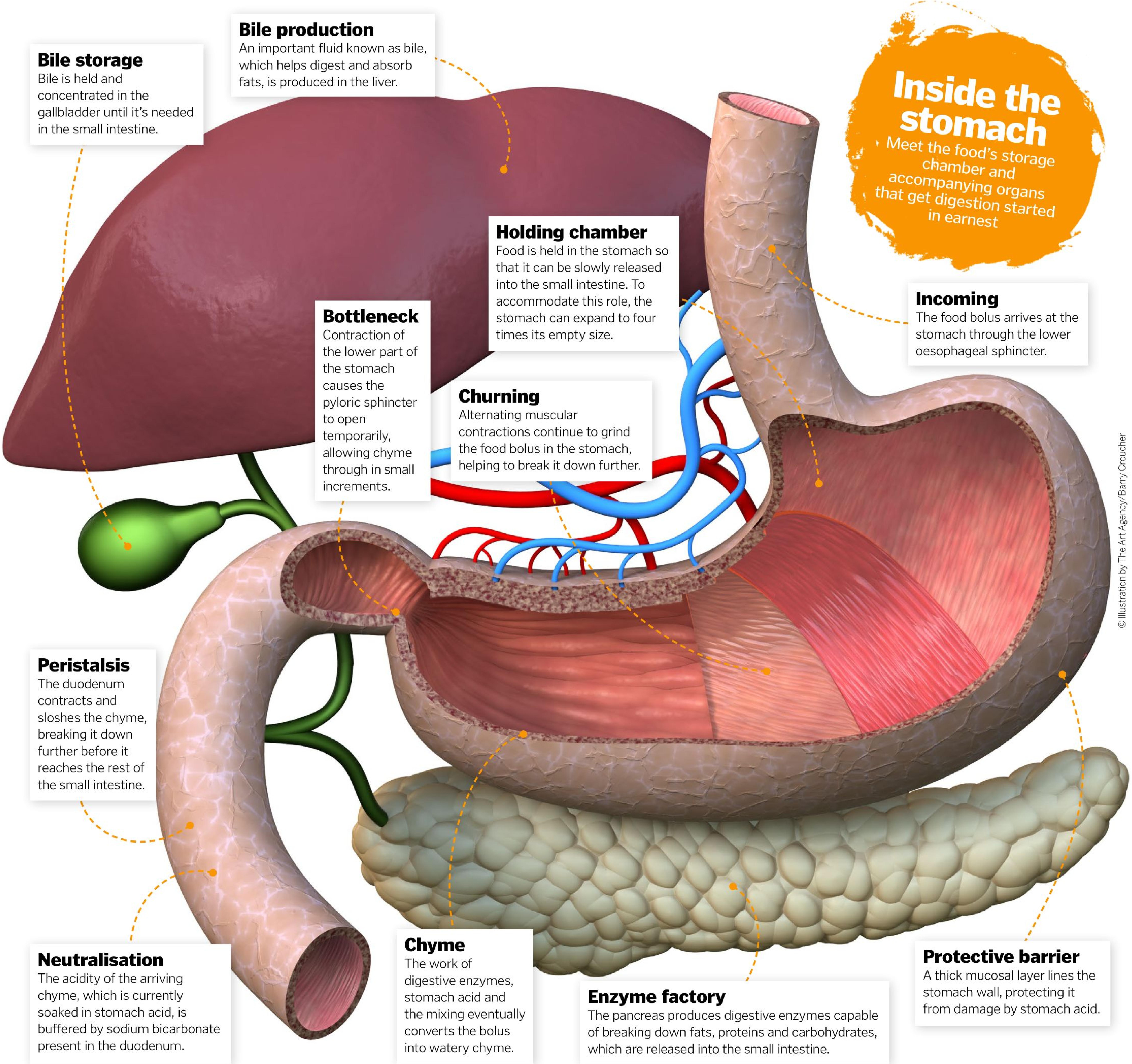
The gut-brain connection

There are around 100 million neurons lining the stomach and other parts of the gut. This massive collection of connections is so expansive that it's often given the colloquial name of 'the second brain'. We've already seen that the brain can impact the stomach as soon as the optic nerves detect food, but this relationship goes both ways. The stomach and other parts of the gut are constantly informing and guiding the brain while we're eating and digesting. If you've ingested a particularly large meal and feel the need to lay down, that's because your digestive tract has drawn away blood supply from other organs. And have you ever had 'butterflies' in your stomach? That signal actually comes from the stomach as a sign of protest when blood is drawn away from the organ.

DID YOU KNOW? *The stomach stops growing once you reach adulthood. When empty it's the same size as your closed fist*

Inside the stomach

Meet the food's storage chamber and accompanying organs that get digestion started in earnest



Bile storage
Bile is held and concentrated in the gallbladder until it's needed in the small intestine.

Bile production
An important fluid known as bile, which helps digest and absorb fats, is produced in the liver.

Holding chamber
Food is held in the stomach so that it can be slowly released into the small intestine. To accommodate this role, the stomach can expand to four times its empty size.

Incoming
The food bolus arrives at the stomach through the lower oesophageal sphincter.

Bottleneck
Contraction of the lower part of the stomach causes the pyloric sphincter to open temporarily, allowing chyme through in small increments.

Churning
Alternating muscular contractions continue to grind the food bolus in the stomach, helping to break it down further.

Peristalsis
The duodenum contracts and sloshes the chyme, breaking it down further before it reaches the rest of the small intestine.

Neutralisation
The acidity of the arriving chyme, which is currently soaked in stomach acid, is buffered by sodium bicarbonate present in the duodenum.

Chyme
The work of digestive enzymes, stomach acid and the mixing eventually converts the bolus into watery chyme.

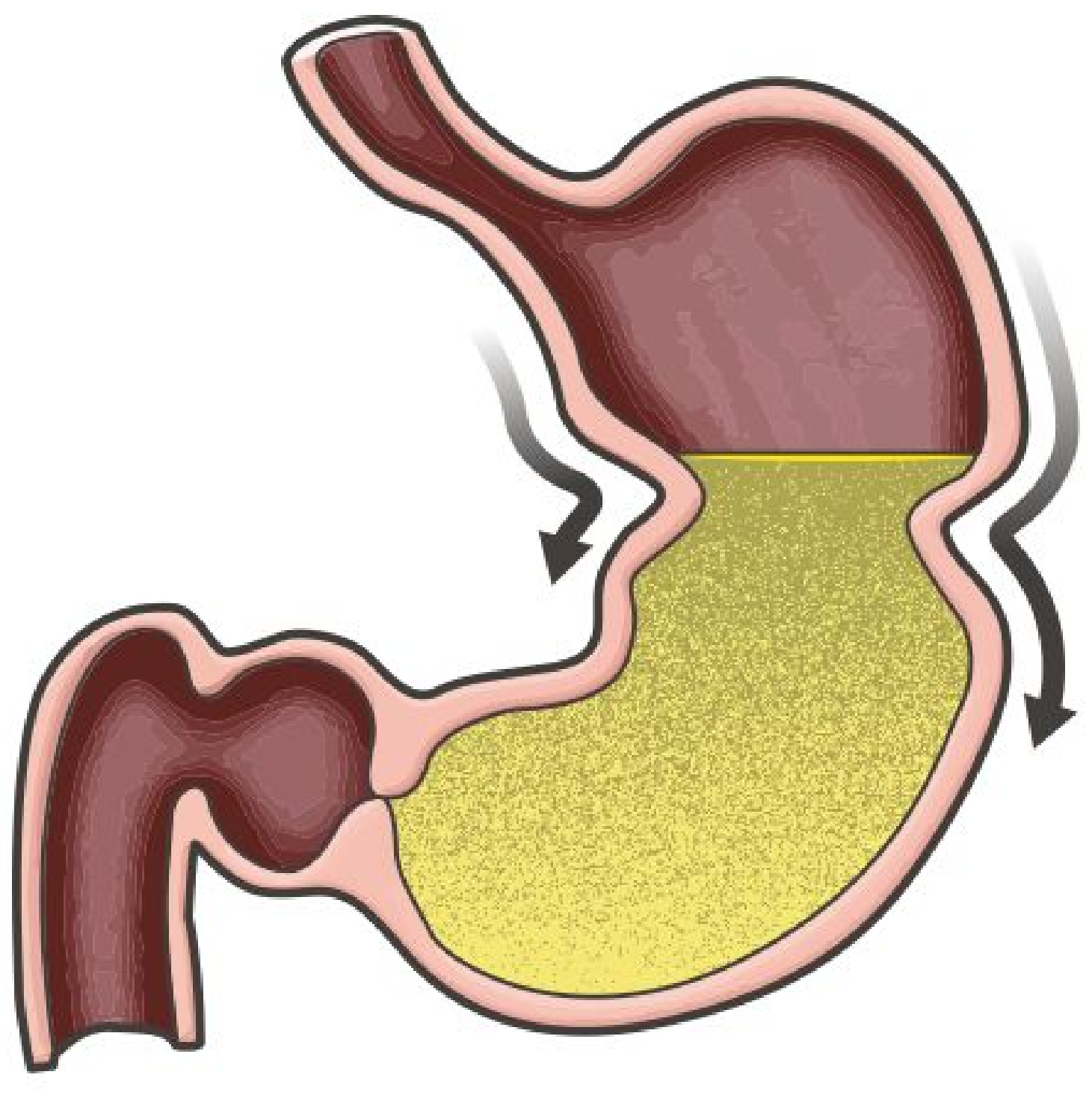
Enzyme factory
The pancreas produces digestive enzymes capable of breaking down fats, proteins and carbohydrates, which are released into the small intestine.

Protective barrier
A thick mucosal layer lines the stomach wall, protecting it from damage by stomach acid.

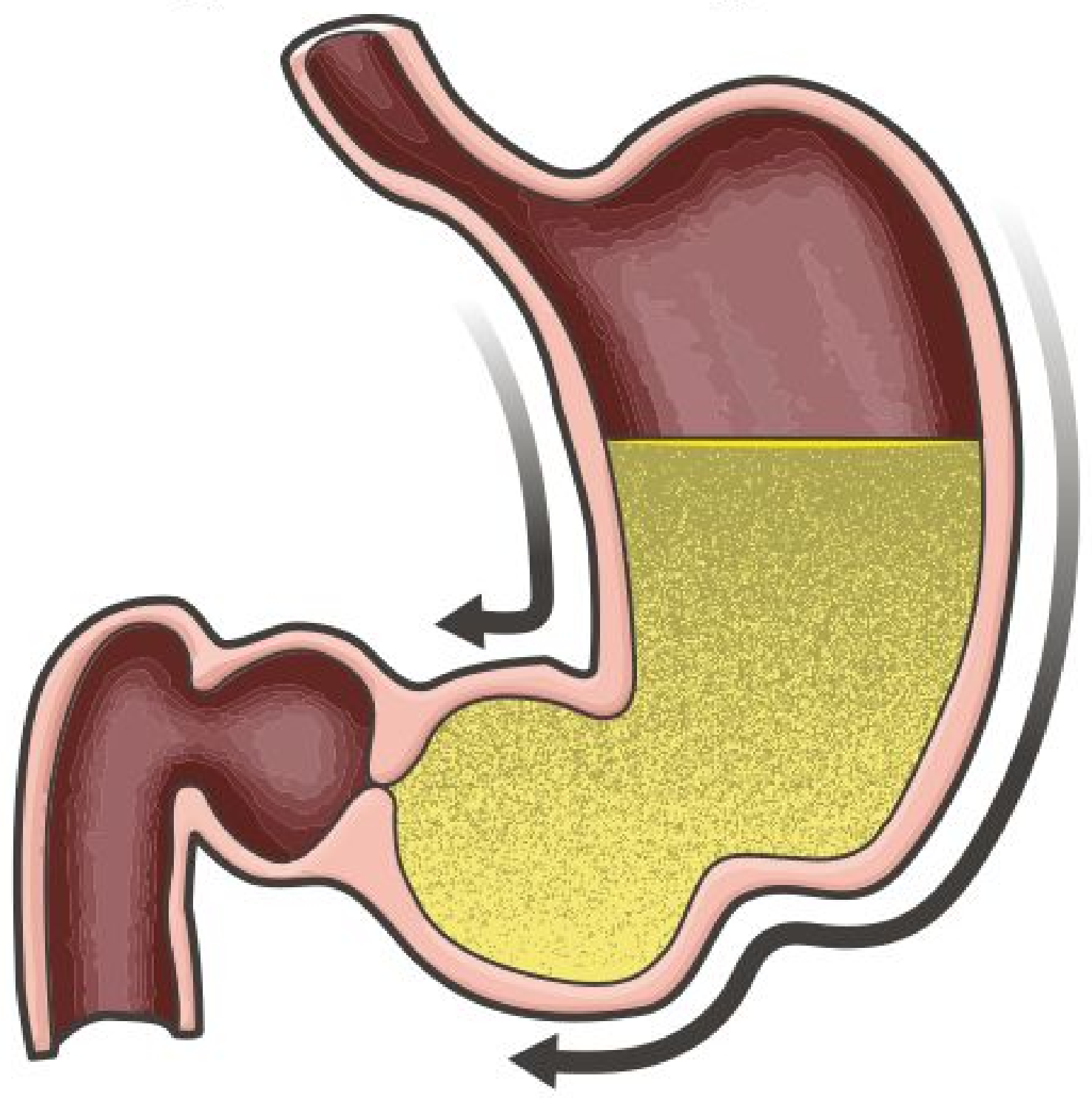
© Illustration by The Art Agency/Barry Croucher

What happens in the stomach?

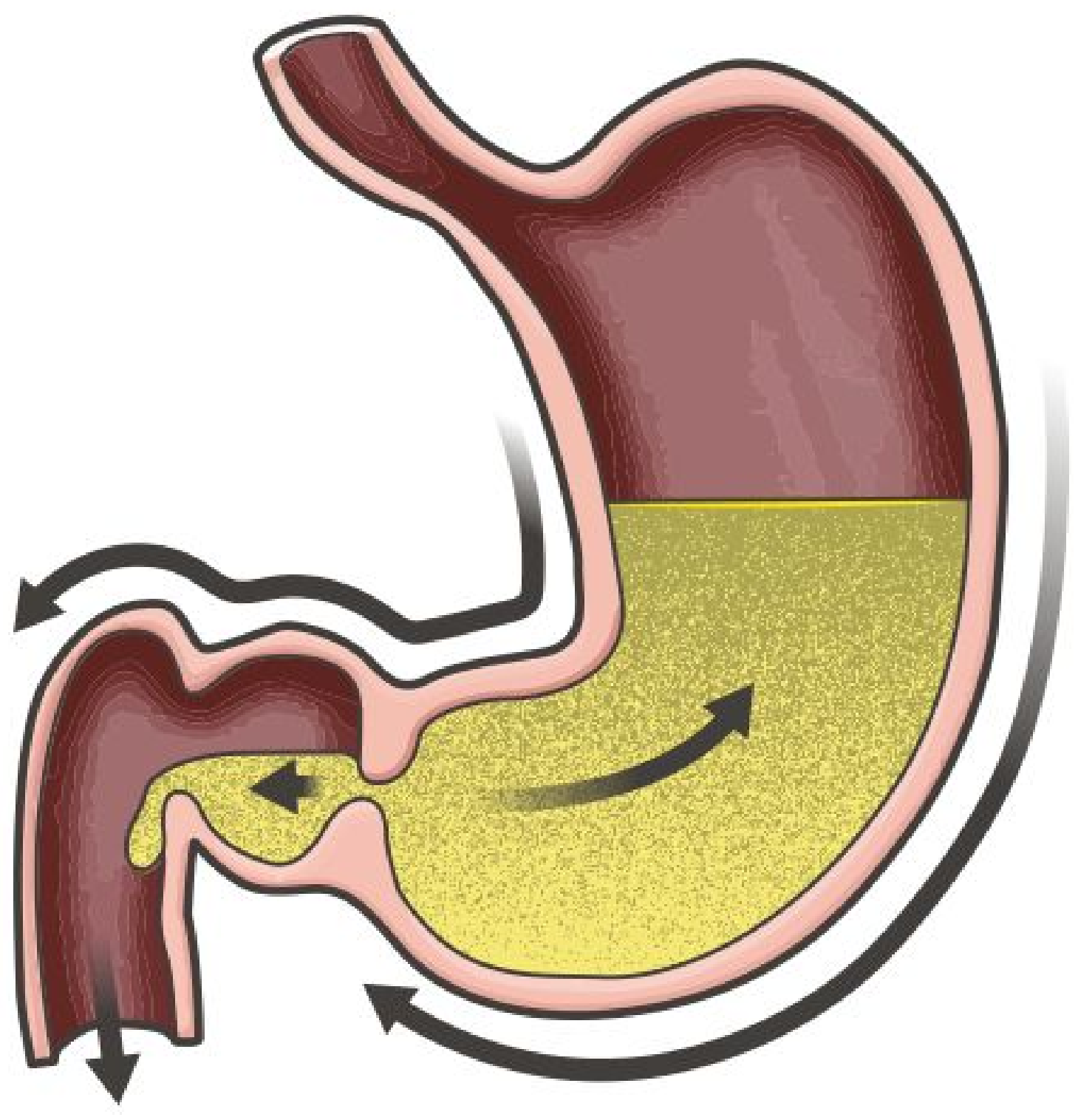
This hollow organ is the mixing-machine of the digestive system



Propulsion
From the oesophagus, peristaltic waves move the food bolus into the stomach, where it collects and meets the stomach acids.



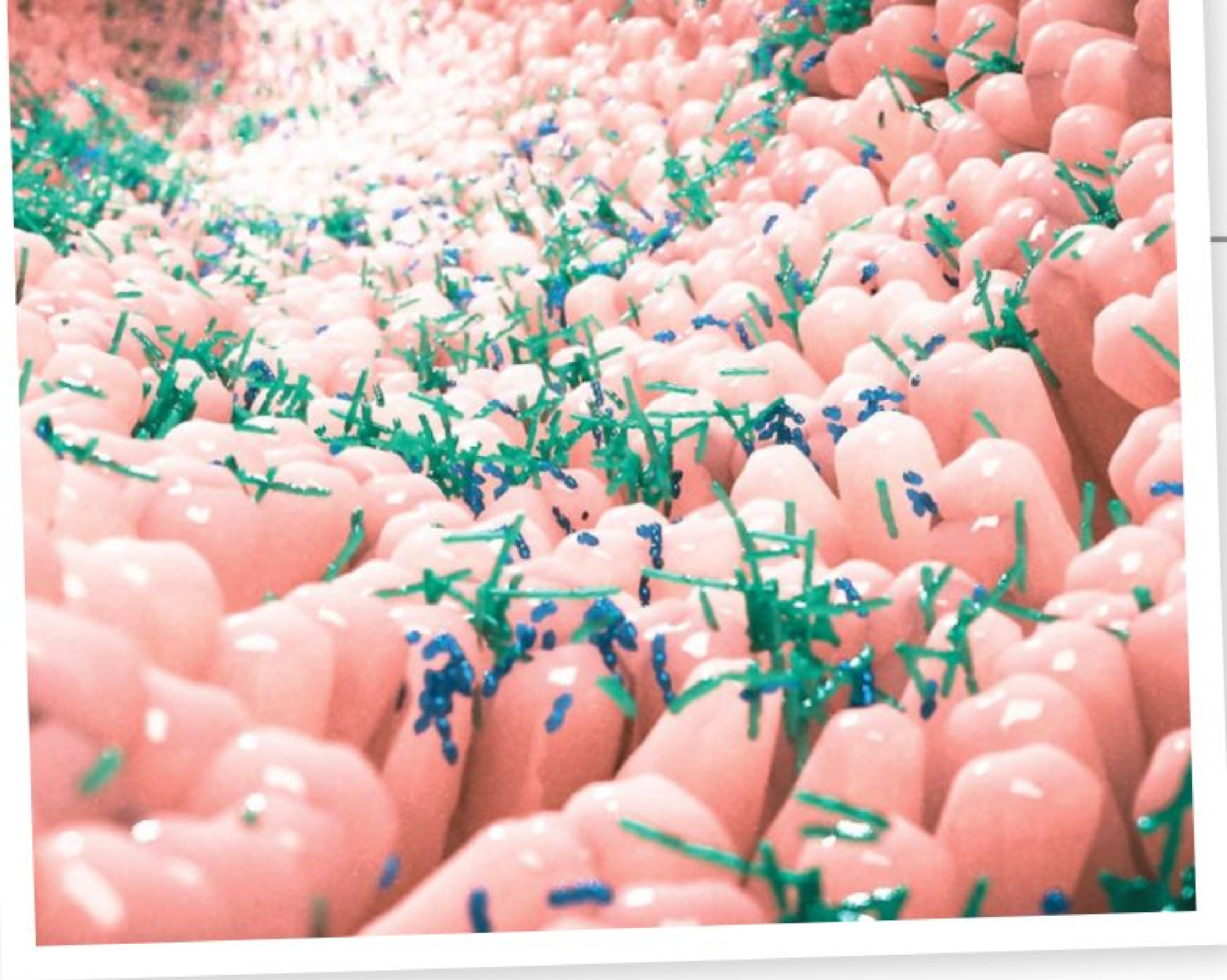
Grinding
Waves of peristalsis move from the fundus (top of the stomach) to pylorus (bottom of the stomach), churning the acids and food into a mixture called chyme.



Retropulsion
Eventually the chyme is pushed through the pylorus into the duodenum, small amounts at a time, while the rest of the contents is pushed back into the stomach.

© Illustration by The Art Agency/Nick Sellers

SMALL + LARGE INTESTINES, BLOODSTREAM & USE OF NUTRIENTS



Your intestinal tract is home to trillions of microorganisms that help in digestion and gut health

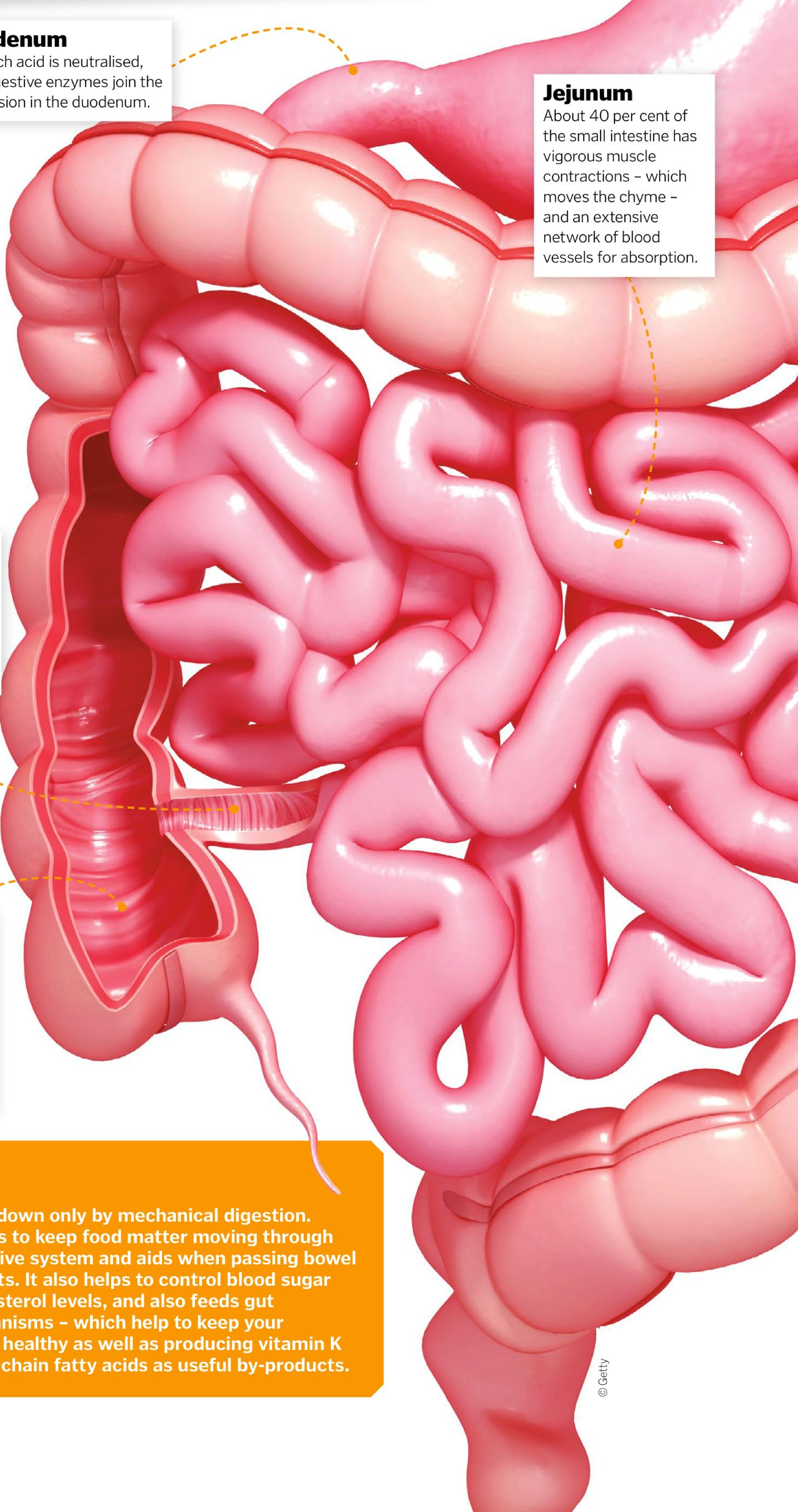
© Shutterstock

You are here

By the time your meal arrives in the small intestine, the delicious feast that it once was has been completely lost. In your mouth, the amylase in your saliva broke down long chains of carbohydrates, and your teeth crushed it into mulch. In your stomach, the food bathed in gastric juices that tore its proteins to pieces while being mashed by the organ's muscles. Now it arrives in the small intestine as a watery mixture with an entourage of fat-digesters, protein-choppers and carbohydrate-gobblers ready to strip any remnants of the form it had once been. In its wake will be left only the component parts – the building blocks that are needed by your cells. These molecules will be absorbed and shepherded around the body.

The importance of the intestinal tract is reflected in its size. Of the roughly nine metres of gastrointestinal tract in the body, six metres is taken up by the small intestine and another 1.5 metres by the large intestine. This leaves plenty of room for molecules to be absorbed as they migrate through the small intestine. Once they've been collected, the proteins, fats, sugars and some vitamins, minerals and salts are transported to the liver for processing.

Now material in the large intestine is approaching the end. This is the last processing point before it will be eliminated as waste.



Duodenum
Stomach acid is neutralised, and digestive enzymes join the procession in the duodenum.

Jejunum
About 40 per cent of the small intestine has vigorous muscle contractions – which moves the chyme – and an extensive network of blood vessels for absorption.

Ileum
The final region of small intestine is narrower, thinner and has less blood supply than the preceding regions.

Time to go
Remaining food matter that enters the large intestine is destined for elimination after any fluid has been recovered.

© Getty

The importance of fibre

Dietary fibre is composed of food matter that our cells are unable to digest and subsequently absorb. You could be forgiven for thinking that fibre is a useless thing for us to ingest, but in reality a healthy intake of fibre can be massively important to gut health. Soluble fibre, which dissolves in water, forms a gel-like substance as it migrates through the gut, whereas insoluble fibre is broken down only by mechanical digestion. Fibre helps to keep food matter moving through the digestive system and aids when passing bowel movements. It also helps to control blood sugar and cholesterol levels, and also feeds gut microorganisms – which help to keep your intestines healthy as well as producing vitamin K and short-chain fatty acids as useful by-products.

DID YOU KNOW? *Your gut microbiome can influence how well or poorly you respond to certain foods and medication*

The long path to absorption

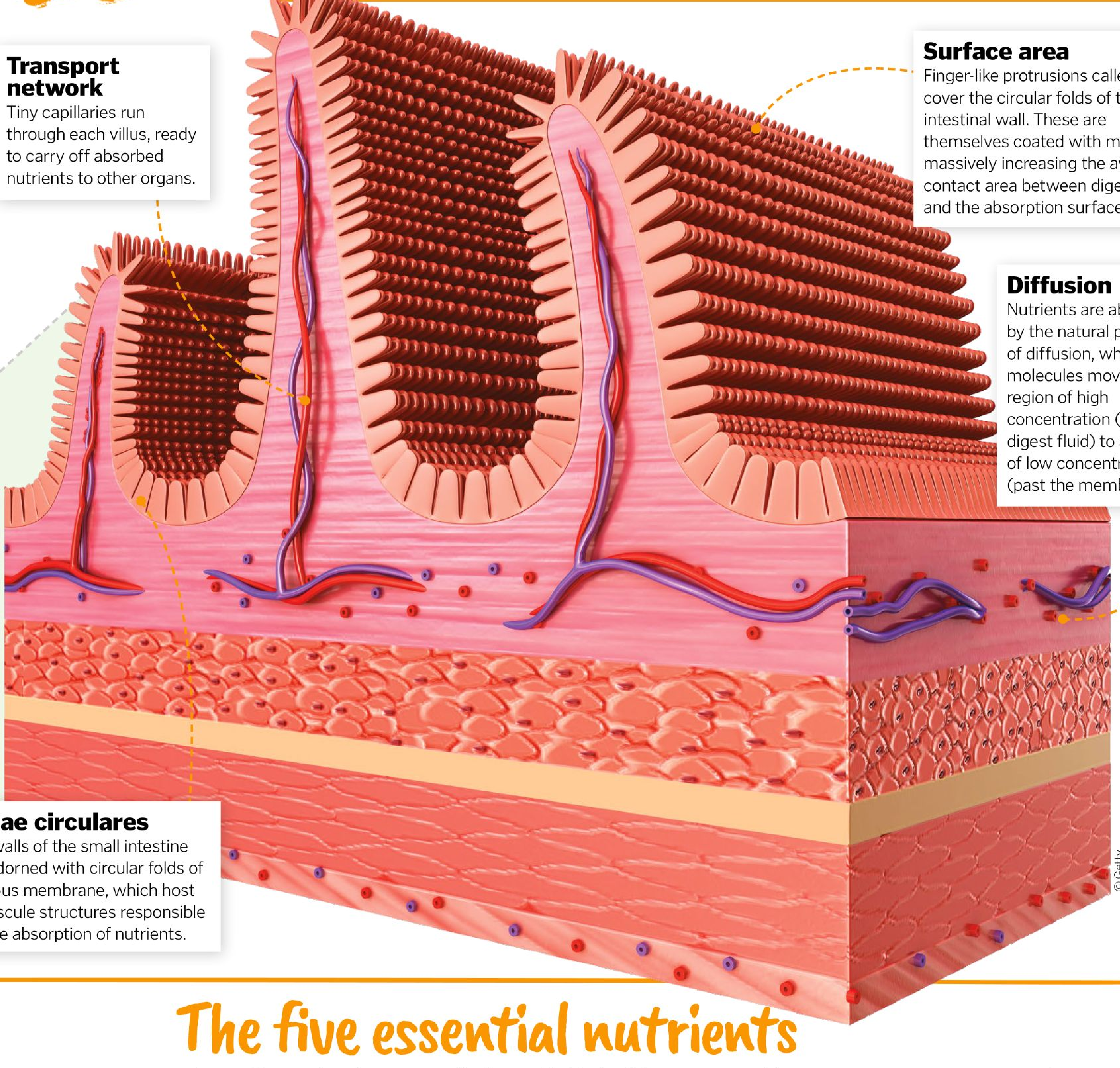
The weaving, undulating corridors of the small intestine are responsible for collecting digested nutrients

Independent action

As we've previously discovered, the gut has its own huge network of neurons. This 'second brain' is more formally recognised as the enteric nervous system, which interacts with the brain through multiple channels, including via the vagus nerve (one of the cranial nerves). But remarkably, action by the enteric nervous system can occur independently of input from the brain.

The action of peristalsis – which describes waves of muscular contraction – has guided the food all the way from the oesophagus to the intestines. And once in the long network of intestinal tubing, peristalsis is more important than ever to shift the chyme through the tract.

Research has shown that the 'second brain' can perform peristalsis independently, which has led some scientists to speculate that it could have been a primitive brain, and thus may have existed first. So perhaps the brain in our head is the true 'second brain'.



Transport network
Tiny capillaries run through each villus, ready to carry off absorbed nutrients to other organs.

Surface area
Finger-like protrusions called villi cover the circular folds of the intestinal wall. These are themselves coated with microvilli, massively increasing the available contact area between digest fluid and the absorption surface.

Diffusion
Nutrients are absorbed by the natural process of diffusion, whereby molecules move from a region of high concentration (the digest fluid) to a region of low concentration (past the membrane).

Plicae circulares
The walls of the small intestine are adorned with circular folds of mucous membrane, which host minuscule structures responsible for the absorption of nutrients.

© Getty

The five essential nutrients

Learn the molecular groups that are vital to building your world

Proteins

Proteins are the workhorses powering chemical reactions inside every cell in the human body. Not only are proteins required to build each muscle and get us moving, they also perform the roles of hormones, enzymes, antibodies and more.

Fats

Fats are often maligned as being unhealthy, but in fact they're an important macronutrient involved in an array of integral processes. They aid in mineral absorption, muscle movement, forming anti-inflammatories, blood clotting and building cells.

Carbohydrates

Carbohydrates are an important resource for energy. The brain operates solely on energy provided by glucose – a basic sugar building block of complex carbohydrates. Carbohydrates are stored as long chains and are harvested for energy during periods of fasting.

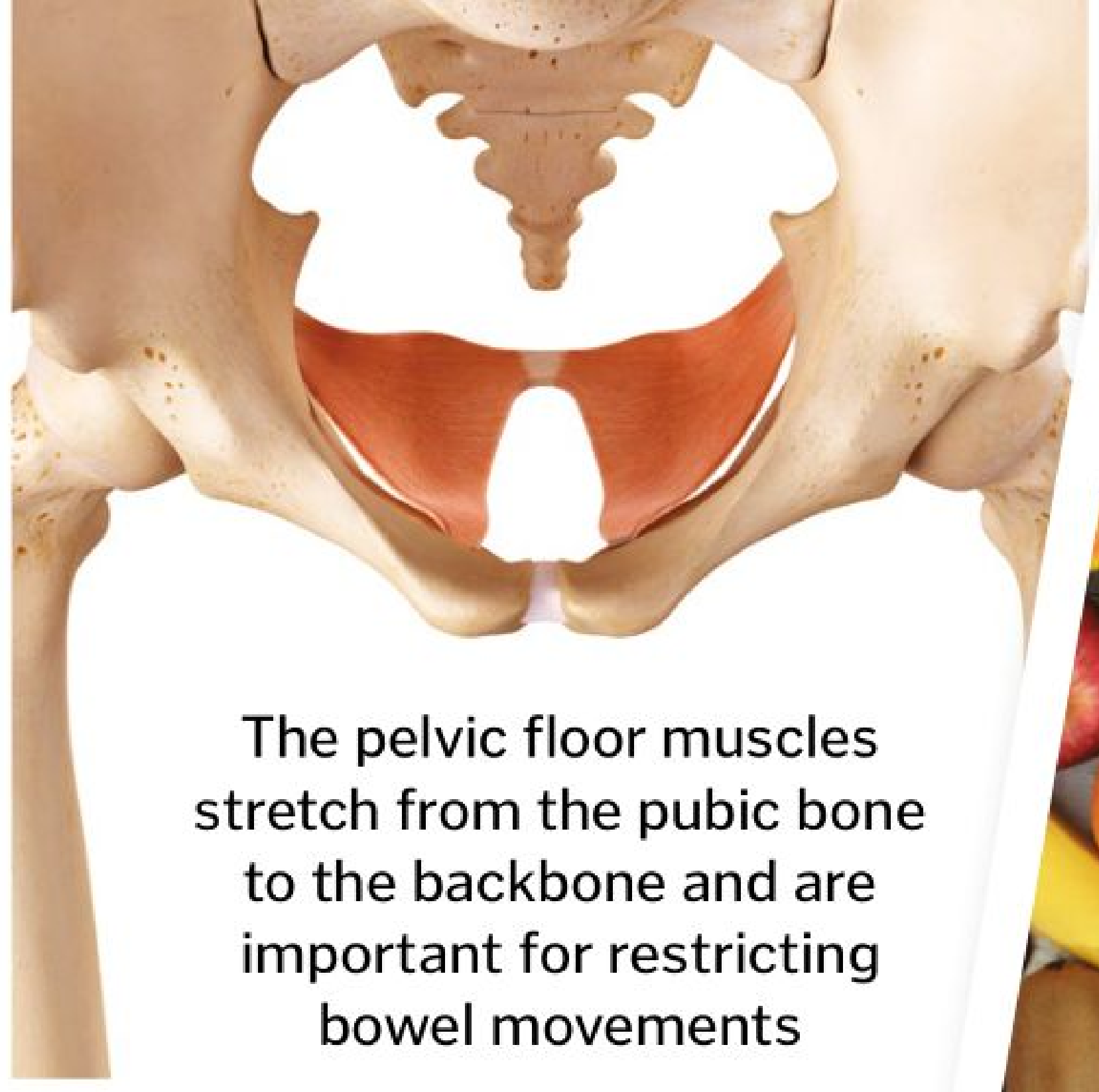
Vitamins

Vitamins are micronutrients that play important supporting roles in many bodily processes. For example, they help store and release energy from food, keep our organs and nervous systems in good working condition and power the immune system.

Minerals

In a similar role to vitamins, minerals are also micronutrients that bolster many of the key processes in the body. For example, they aid in building and keeping our bones strong, regulating metabolic activity and maintaining proper hydration.

RECTUM, SPHINCTER & WASTE



The pelvic floor muscles stretch from the pubic bone to the backbone and are important for restricting bowel movements

© Getty

Wholegrains, vegetables, nuts, seeds, beans, peas and pulses are rich in dietary fibre

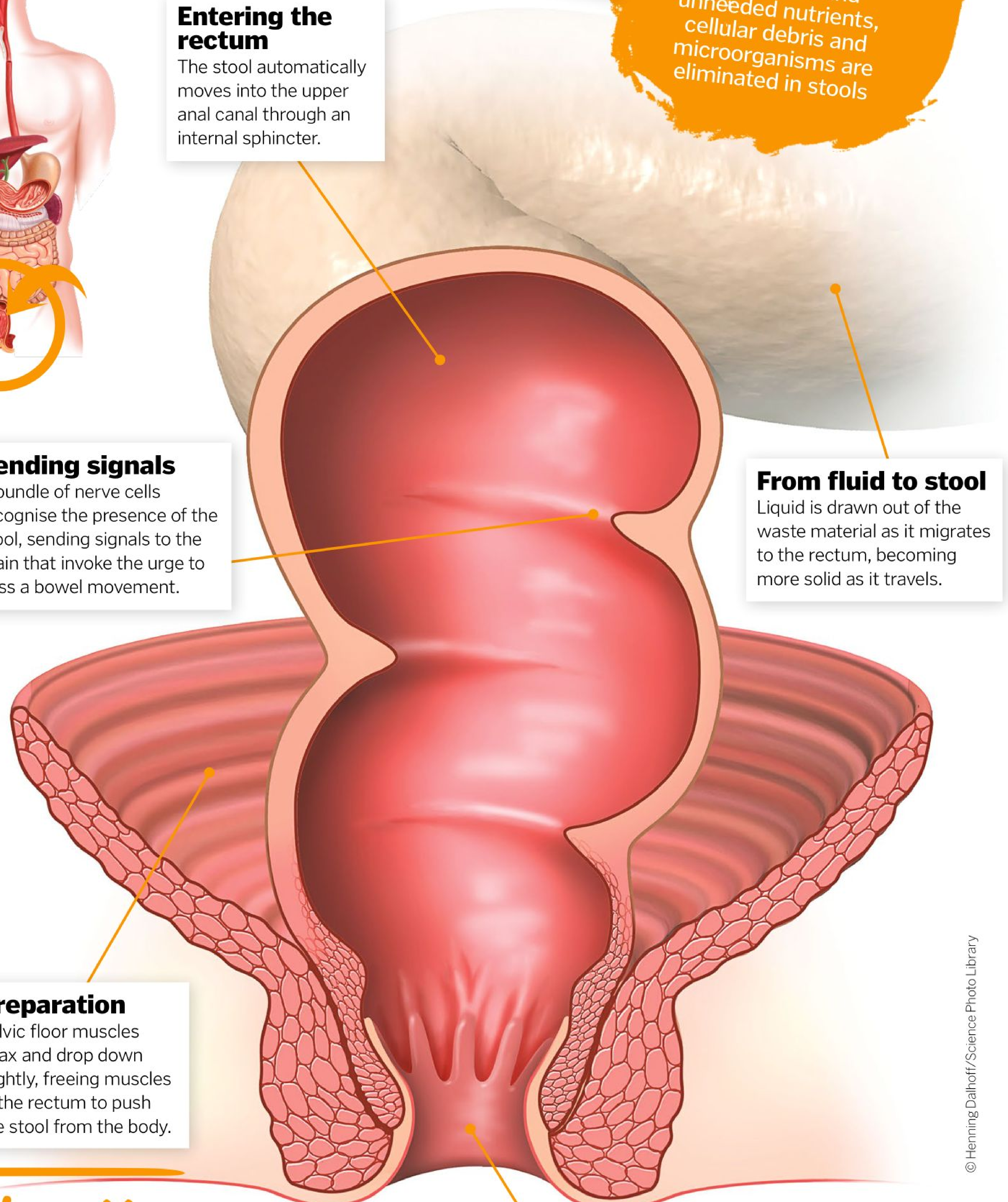
You are here

For a large portion of ingested food matter, it's time for a new start as part of your body. But for the rest waits the long, winding path through the large intestine and the huge number of microorganisms that dwell there. Then it's into the rectum for elimination. But it's not just leftover food matter that's eliminated as stool. On the contrary, alongside food remnants are cellular debris from dead cells that lined the intestinal wall; fibrous materials that have migrated through your entire system largely unscathed; and many members from the gut microorganism community. This diverse ensemble includes bacteria, viruses, fungi and archaea. Together they form a waste product that will provide energy to a suite of new organisms outside of the body.

The final stage of the gastrointestinal tract is of huge importance, primarily because bowel movements ensure the release of toxins from the body. Humans are imperfect creatures with imperfect diets, and it is inevitable that we will not uptake every iota of energy we ingest, so it's integral we maintain healthy organs for elimination. As with the beginning of our food journey, the end is one of the few areas over which we have voluntary control. And just as we take care over what we ingest, we should be careful to ensure our eliminations are regular and comfortable.

Leaving the body

Indigestible and unneeded nutrients, cellular debris and microorganisms are eliminated in stools



Entering the rectum
The stool automatically moves into the upper anal canal through an internal sphincter.

Sending signals
A bundle of nerve cells recognise the presence of the stool, sending signals to the brain that invoke the urge to pass a bowel movement.

From fluid to stool
Liquid is drawn out of the waste material as it migrates to the rectum, becoming more solid as it travels.

Preparation
Pelvic floor muscles relax and drop down slightly, freeing muscles in the rectum to push the stool from the body.

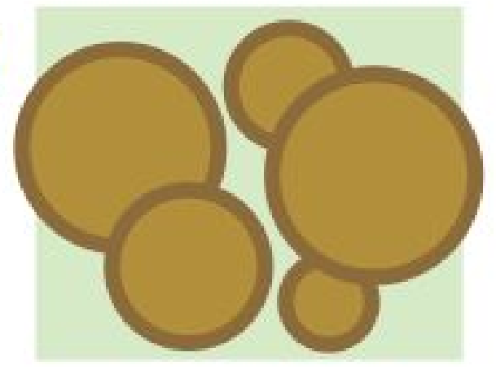
Elimination
The external sphincter is under voluntary control, and when consciously decided upon can be opened, allowing the stool to pass from the body.

© Henning Dalhoff/Science Photo Library

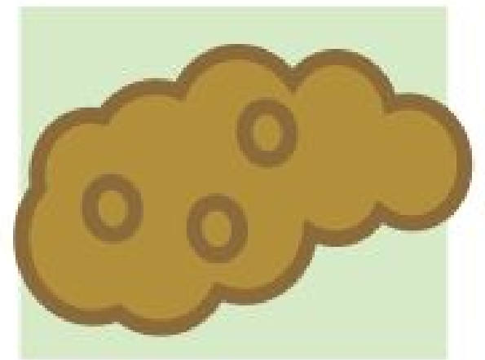
> "It's not just leftover food matter that's eliminated as stool"

What your poo says about you

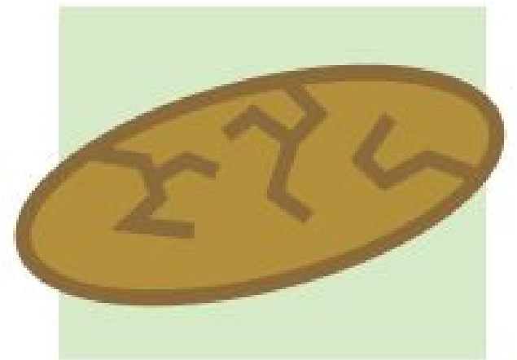
Doctors use the Bristol Stool Chart to grade their patients' poos



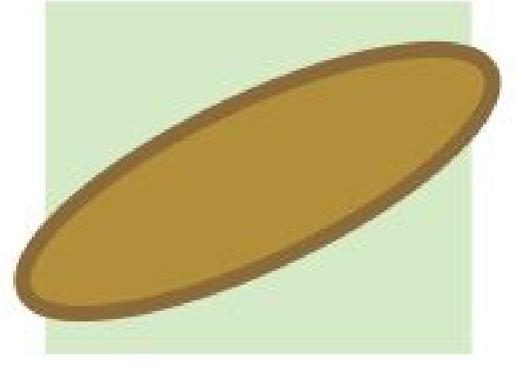
Type 1
Separate hard lumps
SEVERE CONSTIPATION



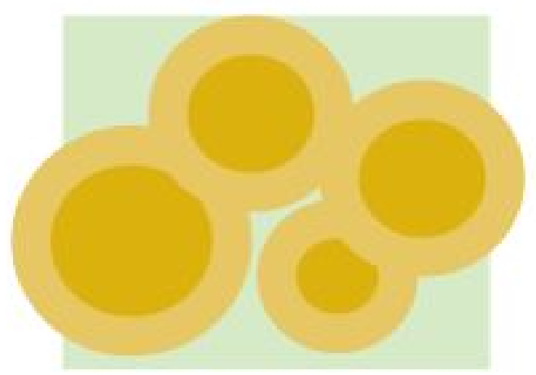
Type 2
Lumpy and sausage-like
MILD CONSTIPATION



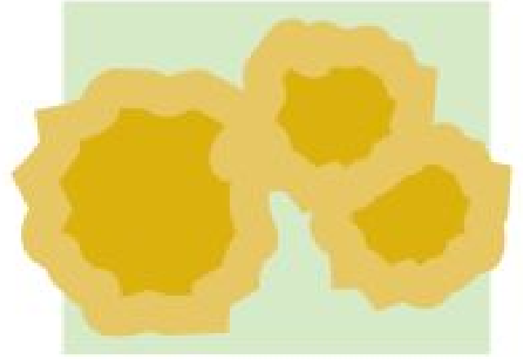
Type 3
A sausage shape with cracks in the surface
NORMAL



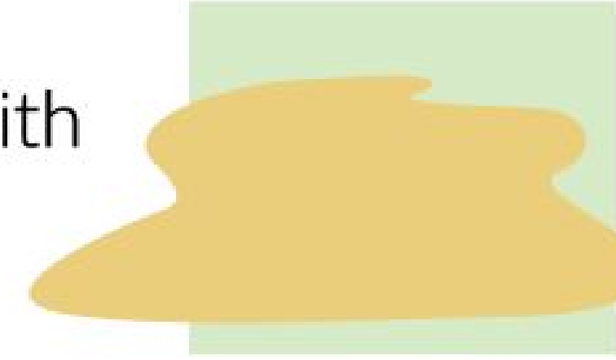
Type 4
Like a smooth, soft sausage or snake
NORMAL



Type 5
Soft blobs with clear-cut edges
LACKING FIBRE



Type 6
Mushy consistency with ragged edges
MILD DIARRHOEA



Type 7
Liquid consistency with no solid pieces
SEVERE DIARRHOEA

GO BACK IN TIME WITH AMAZING HISTORY

Uncover the people, events and inventions that have shaped the modern world, from prehistoric bog bodies to NASA's creations in this new bookazine from the makers of How It Works.

NEW
EXPLORE THE INCREDIBLE PEOPLE, EVENTS & INVENTIONS THAT HAVE SHAPED OUR WORLD
AMAZING HISTORY
ON SALE NOW
UNCOVER 10,000 YEARS OF WORLD HISTORY
FROM THE MAKERS OF HOW IT WORKS
INDUSTRY & INVENTIONS
INFLUENTIAL FIGURES
ANCIENT HISTORY
HOW IT WORKS AMAZING HISTORY
ISBN 978-1-83850-445-8
FIRST EDITION
FUTURE

FUTURE

Ordering is easy. Go online at:

www.myfavouritemagazines.co.uk

Or get it from selected supermarkets & newsagents

What makes muscles strong?

With every simple move we make our muscle cells are working overtime

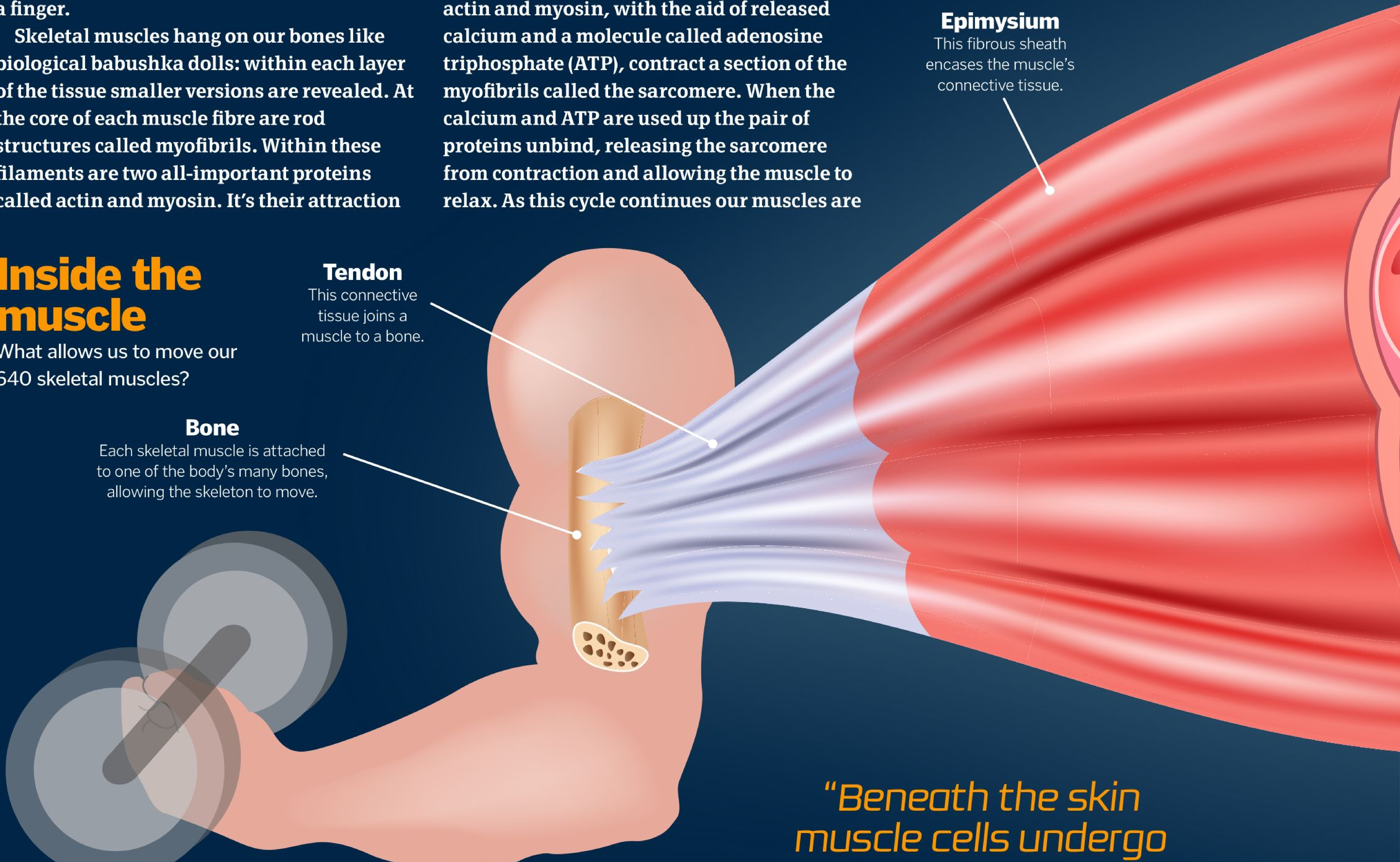
Moving our limbs seems like a relatively simple task. Whether it's picking up a cup of tea or taking a walk, the process of movement appears instant and without much thought. However, beneath the skin our skeletal muscle cells are undergoing an extensive process to simply lift a finger.

Skeletal muscles hang on our bones like biological babushka dolls: within each layer of the tissue smaller versions are revealed. At the core of each muscle fibre are rod structures called myofibrils. Within these filaments are two all-important proteins called actin and myosin. It's their attraction to one another that is responsible for the contracting and relaxing of muscles. However, it's only after a chain reaction of molecules is released throughout the tissue that the pair are allowed to come to together.

These proteins interact in what is known as the sliding filament model or theory. The actin and myosin, with the aid of released calcium and a molecule called adenosine triphosphate (ATP), contract a section of the myofibrils called the sarcomere. When the calcium and ATP are used up the pair of proteins unbind, releasing the sarcomere from contraction and allowing the muscle to relax. As this cycle continues our muscles are able to animate our bodies. The collective tissue pulls the muscle together, then connective tissue called tendons, which grip the surrounding bone, follow suit. When the muscle contracts the two attached bones are pulled together and thus produce movement.

Inside the muscle

What allows us to move our 640 skeletal muscles?

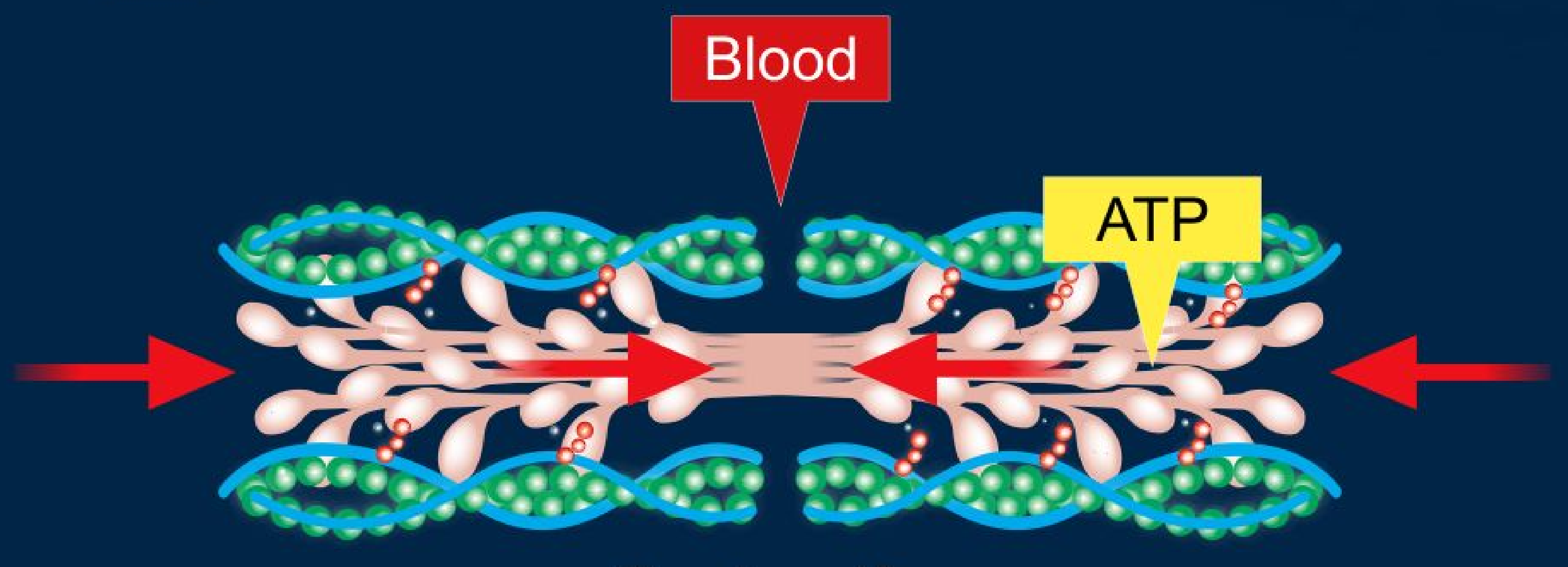


Epimysium
This fibrous sheath encases the muscle's connective tissue.

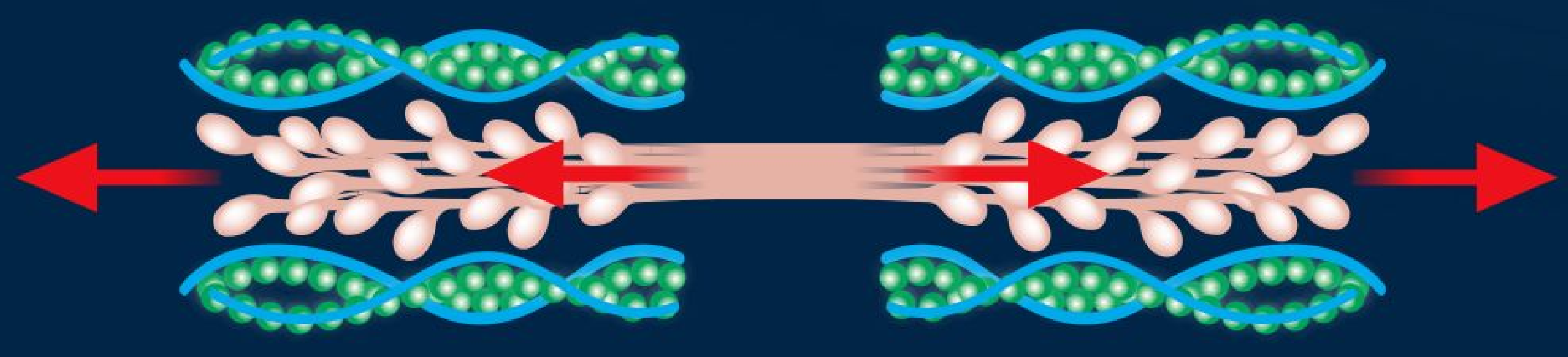
Tendon
This connective tissue joins a muscle to a bone.

Bone
Each skeletal muscle is attached to one of the body's many bones, allowing the skeleton to move.

> *"Beneath the skin muscle cells undergo an extensive process"*



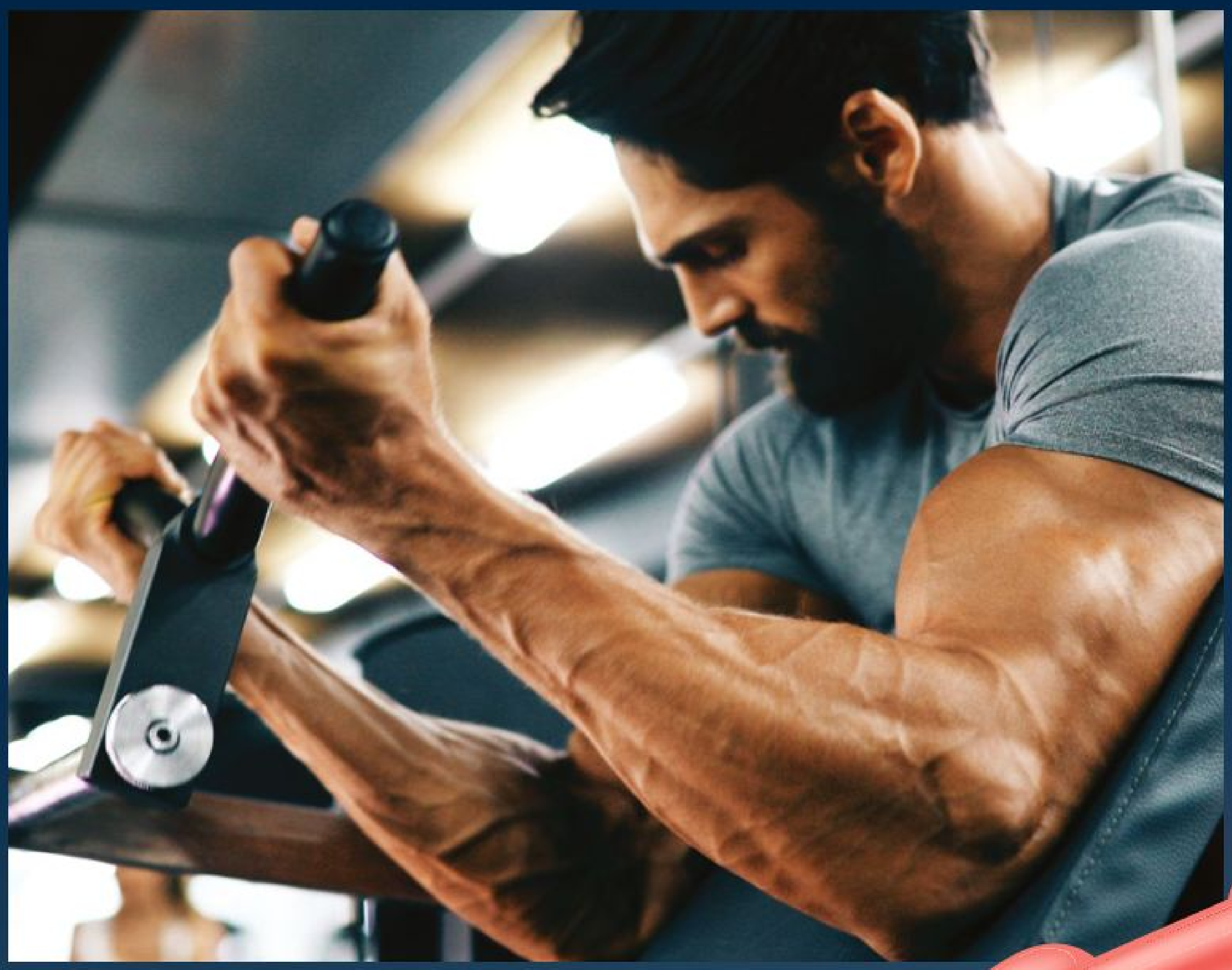
Contraction
Calcium released into the myofibril binds with the tropomyosin and troponin, allowing myosin to bind. ATP is also delivered from neighbouring mitochondria, which binds to the myosin head to create a shape compatible with the actin. When the two are bound the filament becomes shorter and therefore contracts.



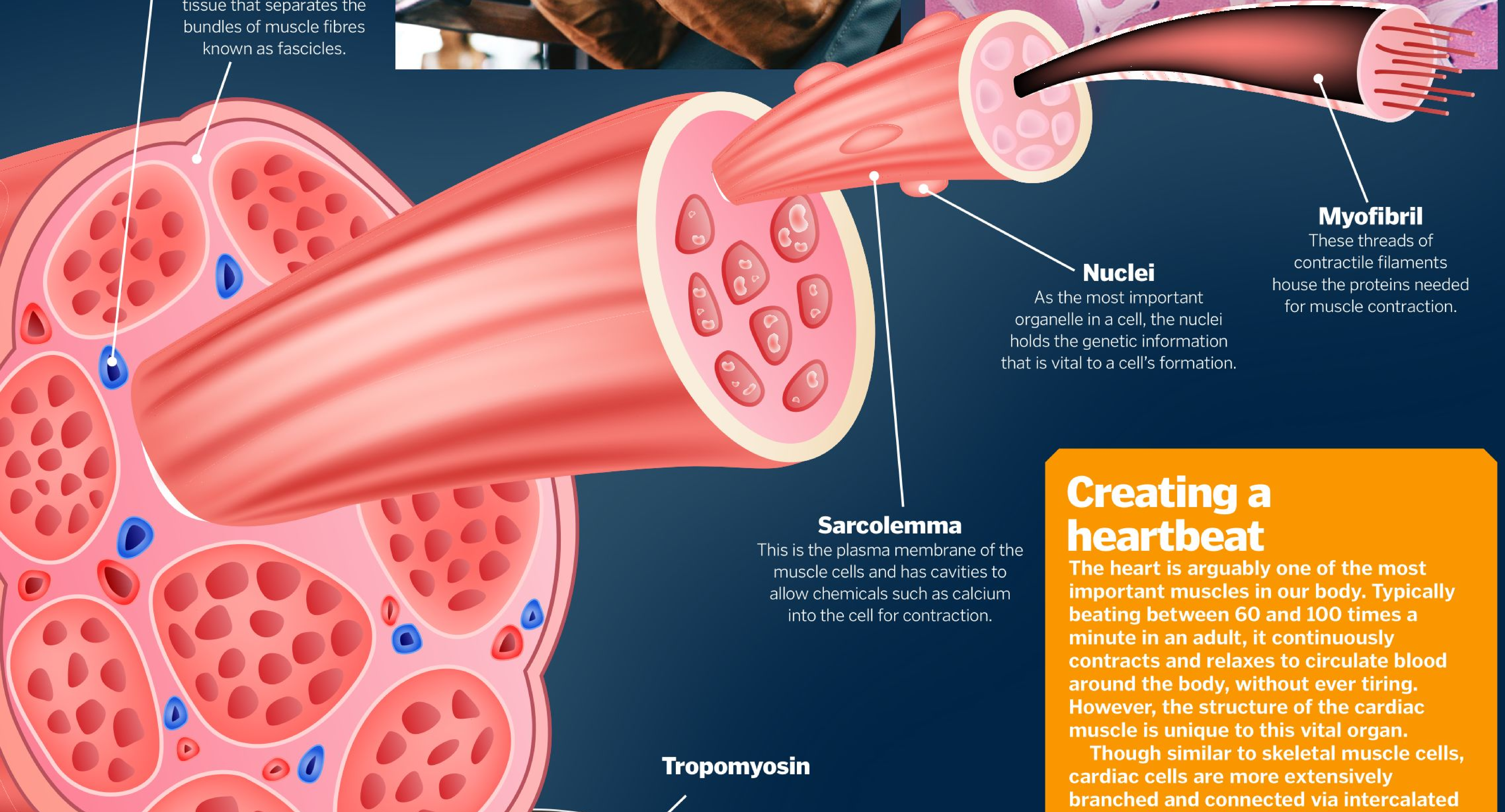
Relaxation
Once the ATP and calcium are used up the actin and myosin cannot interact, resulting in the actin-myosin bond being broken. This causes the muscle to relax and therefore lengthens.

DID YOU KNOW? *The smallest muscle in the body is the stapedius, located inside the ear, and measures just over 1mm*

Muscles make up around 40 per cent of a human's body weight



The endomysium holds within it bundles of myofibril fibres for muscle contraction



Blood vessels
These vessels deliver oxygen through red blood cells to the muscle cells.

Perimysium
This is more connective tissue that separates the bundles of muscle fibres known as fascicles.

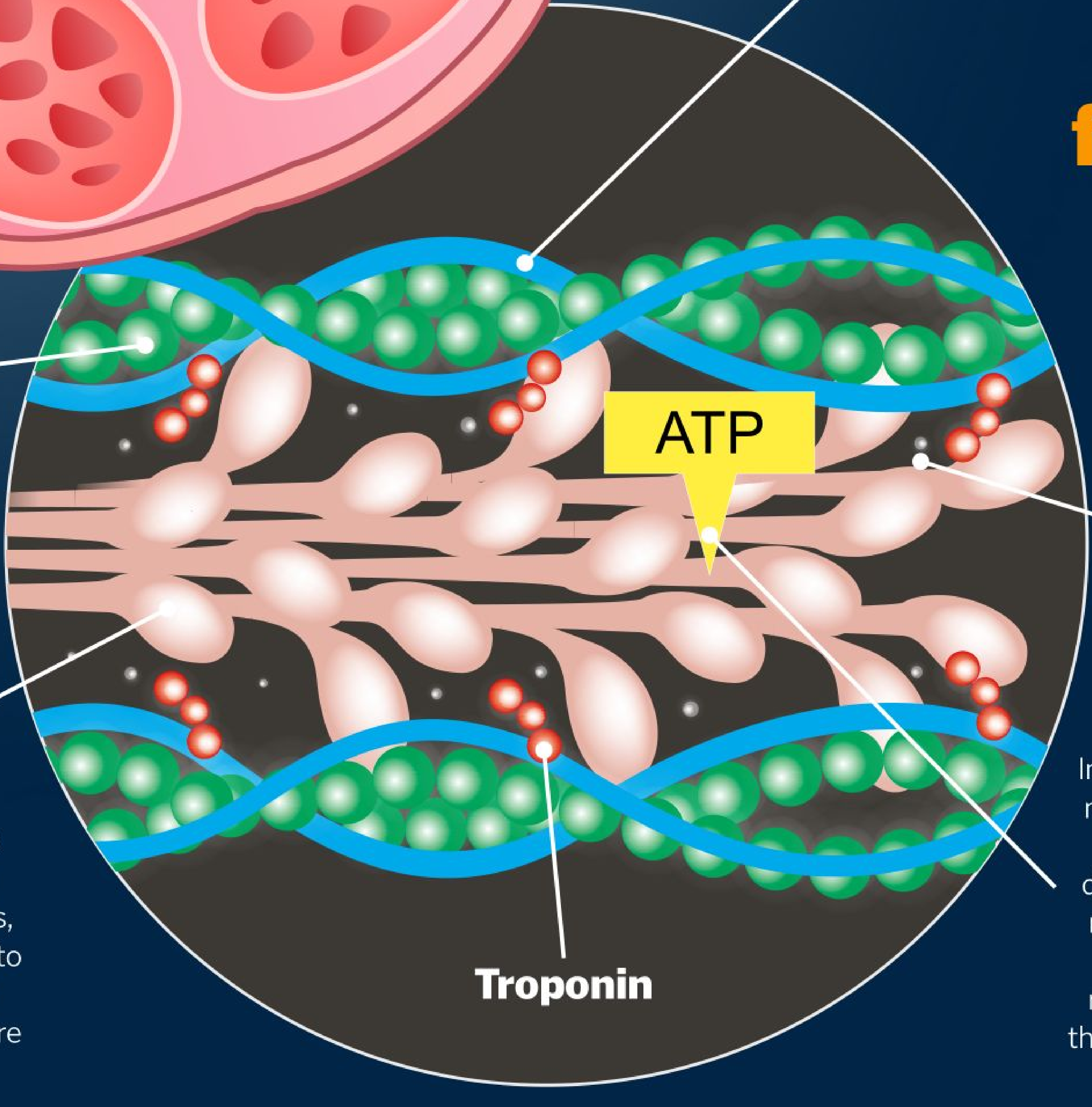
Nuclei
As the most important organelle in a cell, the nuclei holds the genetic information that is vital to a cell's formation.

Myofibril
These threads of contractile filaments house the proteins needed for muscle contraction.

Sarcolemma
This is the plasma membrane of the muscle cells and has cavities to allow chemicals such as calcium into the cell for contraction.

Sliding filament model

Discover the mechanics behind our muscles



Tropomyosin

Actin
This beadlike protein is twisted together to form a filament.

Myosin
A thick protein filament with protuding heads, this is designed to bind with the beadlike structure of the actin.

Troponin

Ca^{2+}

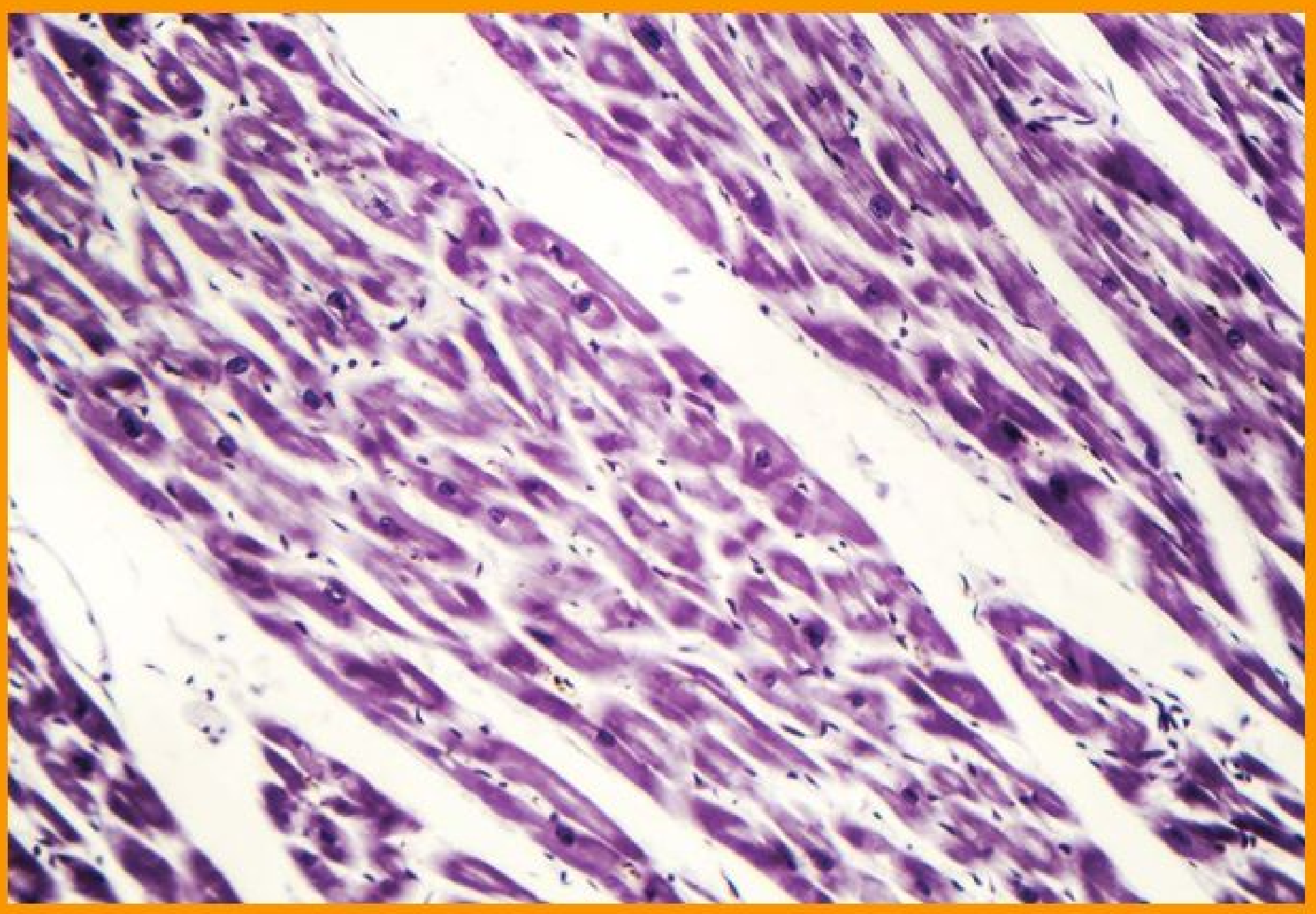
Impulse
Impulses sent via motor neurons travel down to the myofibril and by doing so trigger a chain reaction of events, the final one being the release of calcium and the delivery of ATP within the myofibril.

Creating a heartbeat

The heart is arguably one of the most important muscles in our body. Typically beating between 60 and 100 times a minute in an adult, it continuously contracts and relaxes to circulate blood around the body, without ever tiring. However, the structure of the cardiac muscle is unique to this vital organ.

Though similar to skeletal muscle cells, cardiac cells are more extensively branched and connected via intercalated discs. These discs allow the cardiac muscle cells to move like a wave rather than in a linear motion as skeletal muscle cells do. This wave motion is what allows the heart to become a pump.

Though there is a need for electrical impulses to cause contraction, heartbeats are controlled by the autonomic nervous system (ANS), whereby electrical signals activate muscle cells without conscious thought.



Cardiac cells contract to enable the heart to pump. The average heart beats 100,000 times a day

© Getty

How aerosols turn liquid into gas

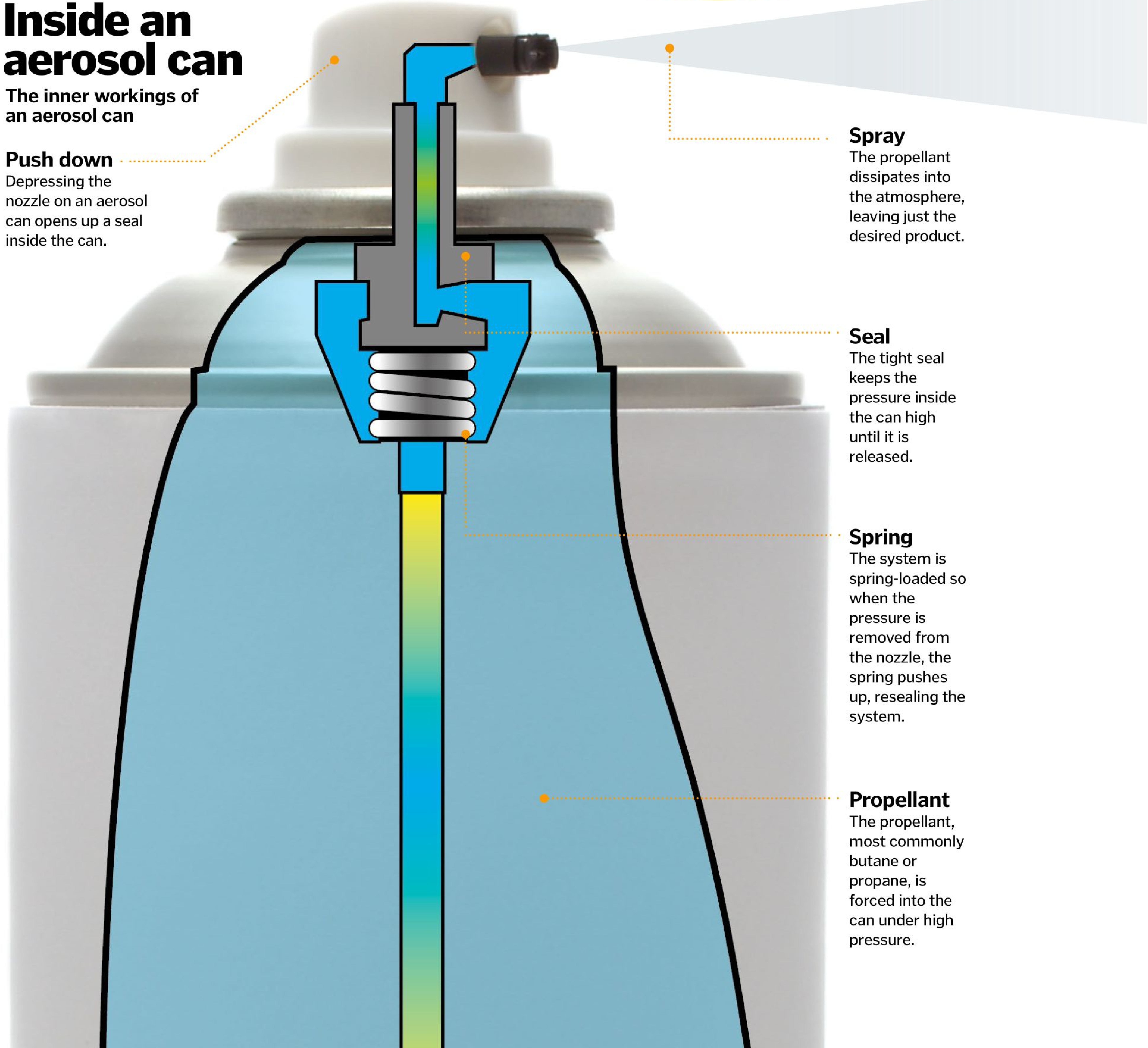
The science behind how aerosols spray everything from deodorant to whipped cream

Aerosol sprays can be used for everything from spray painting to topping cakes

Aerosol cans are highly pressurised cylinders that use a gaseous propellant to expel their contents. The more common system is the liquefied gas system. Liquid product gets poured into the can before the propellant is forced in through the nozzle at somewhere between two and eight times its normal atmospheric pressure. Aerosol propellant was originally made from chlorofluorocarbons (CFCs), but as they are hazardous to the ozone layer, liquefied propane and butane are generally used now. The propellant has a boiling point lower than room temperature, but the intense pressure it is under stops it from boiling. Depressing the nozzle opens up an airtight seal, releasing the pressure. As the pressure is reduced the propellant boils and breaks up the product, forming a gas mixture of propellant and product. This gets pushed out through the newly created gap and out of the nozzle in the form of a fine spray. The pressure is reduced as the volume of product and propellant decreases, which is why each spray is slightly less forceful than the previous one. Thicker substances like shaving cream work in the same way but when the propellant is forced out it forms bubbles inside the product instead of dissipating, creating a foamy result. The exception to this is aerosol cans in which food, such as whipped cream, is stored. Propane and butane are not safe to ingest, so liquefied nitrous oxide, otherwise known as laughing gas, is used instead. Aerosol cans are traditionally made from a thin sheet of steel or aluminium wrapped in rust-resistant tin. The cylinder is wrapped around a curved steel base and welded shut at the end to ensure the high-pressure gas cannot escape.

Inside an aerosol can

The inner workings of an aerosol can



Push down
Depressing the nozzle on an aerosol can opens up a seal inside the can.

Spray
The propellant dissipates into the atmosphere, leaving just the desired product.

Seal
The tight seal keeps the pressure inside the can high until it is released.

Spring
The system is spring-loaded so when the pressure is removed from the nozzle, the spring pushes up, resealing the system.

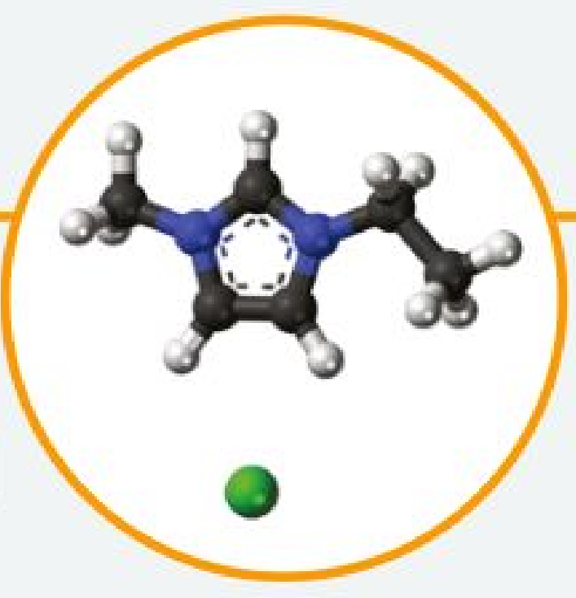
Propellant
The propellant, most commonly butane or propane, is forced into the can under high pressure.

KEY DATES

HISTORY OF THE AEROSOL CAN

1790
The first pressurised cans containing liquid come from France, used to hold carbonated drinks.

1899
The first aerosol is patented by Helbling and Pertsch, for methyl and ethyl chloride.

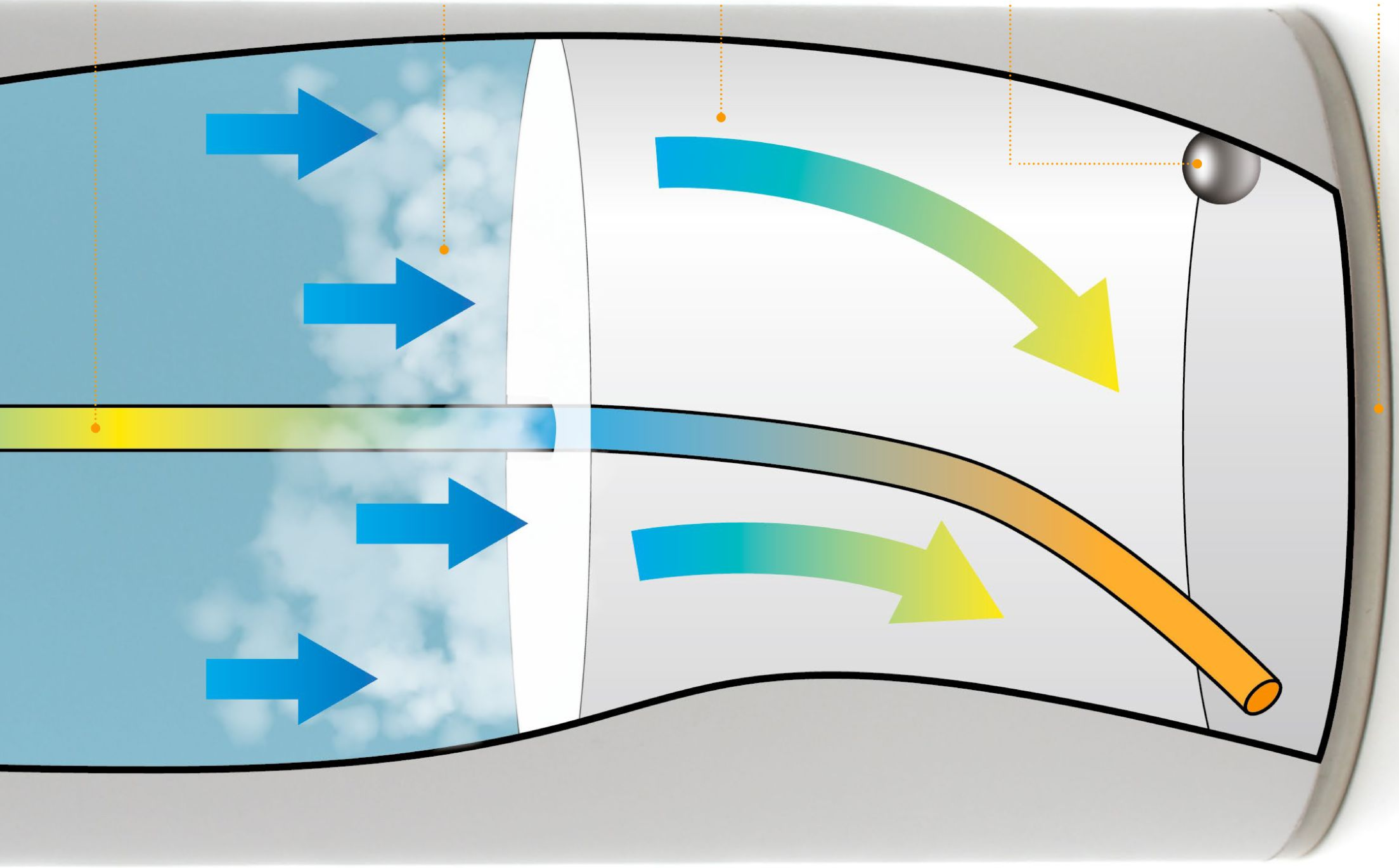


1927
The first aerosol can is patented. Norwegian Erik Rotheim combines a pressurised can and valve system to dispense a product.

1943
Improved by Dr Lyle Goodhue, aerosol cans prove their worth during WWII by holding mosquito-killing spray.

1987
The Montreal Protocol bans the use of CFCs in aerosols after their destructive effect on the ozone layer is discovered.

DID YOU KNOW? *Thomas Midgley Jr, the inventor of CFCs present in early aerosol cans, also invented poisonous leaded petrol*



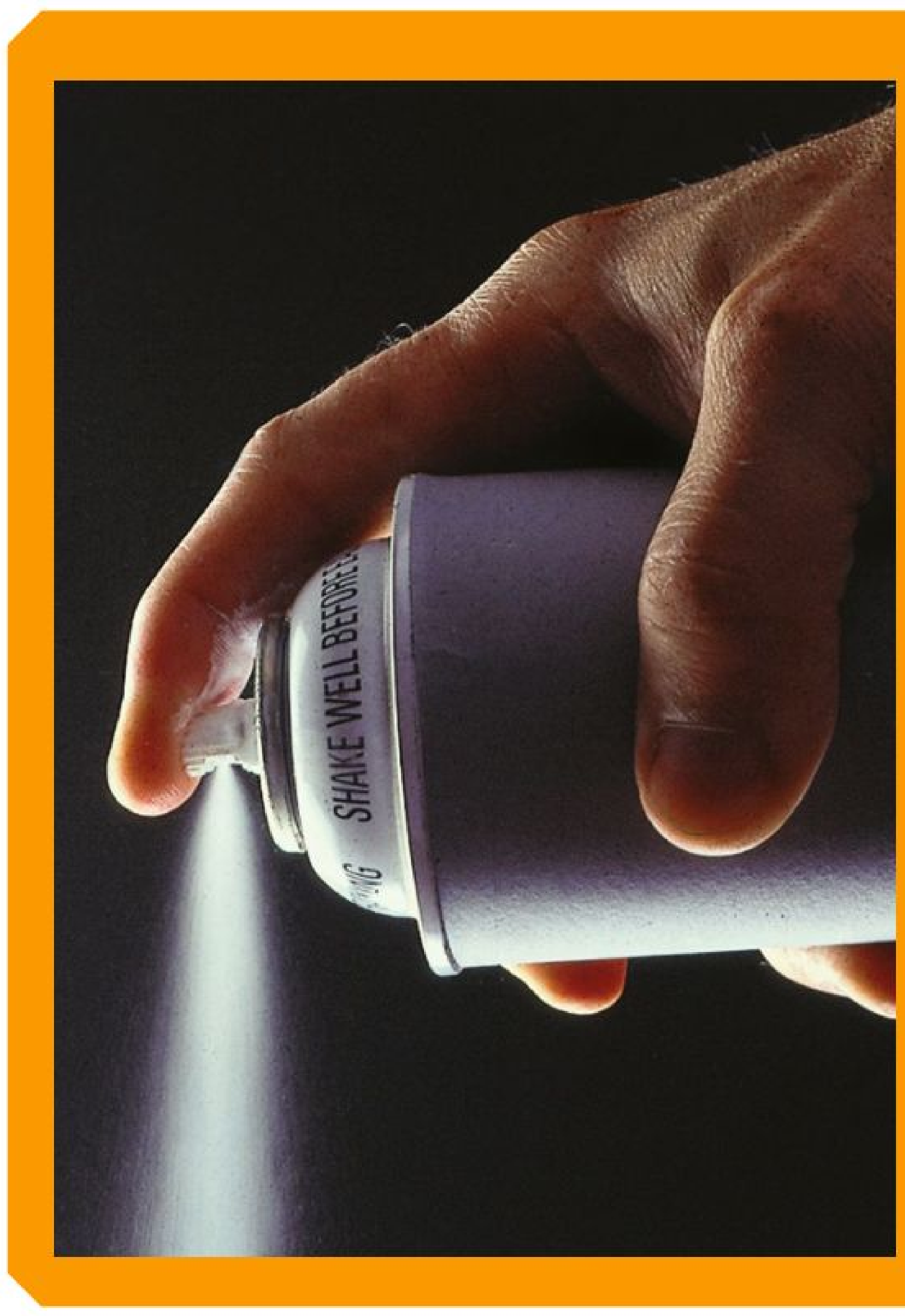
Boiling When the seal is opened, the propellant boils, atomising the product and pushing it out of the nozzle in the form of a spray.

Mix-up Where they meet, the liquefied propellant merges with the liquid product to create a mixture.

Product The product you want to dispense gets poured into the can in liquid form and gets forced downward by the gas.

Ball bearing Some aerosol cans contain a ball bearing that rattles around when shaken, mixing up the propellant and product.

Base The base of most aerosol cans is curved inward to counteract the pressure exerted inside the can.

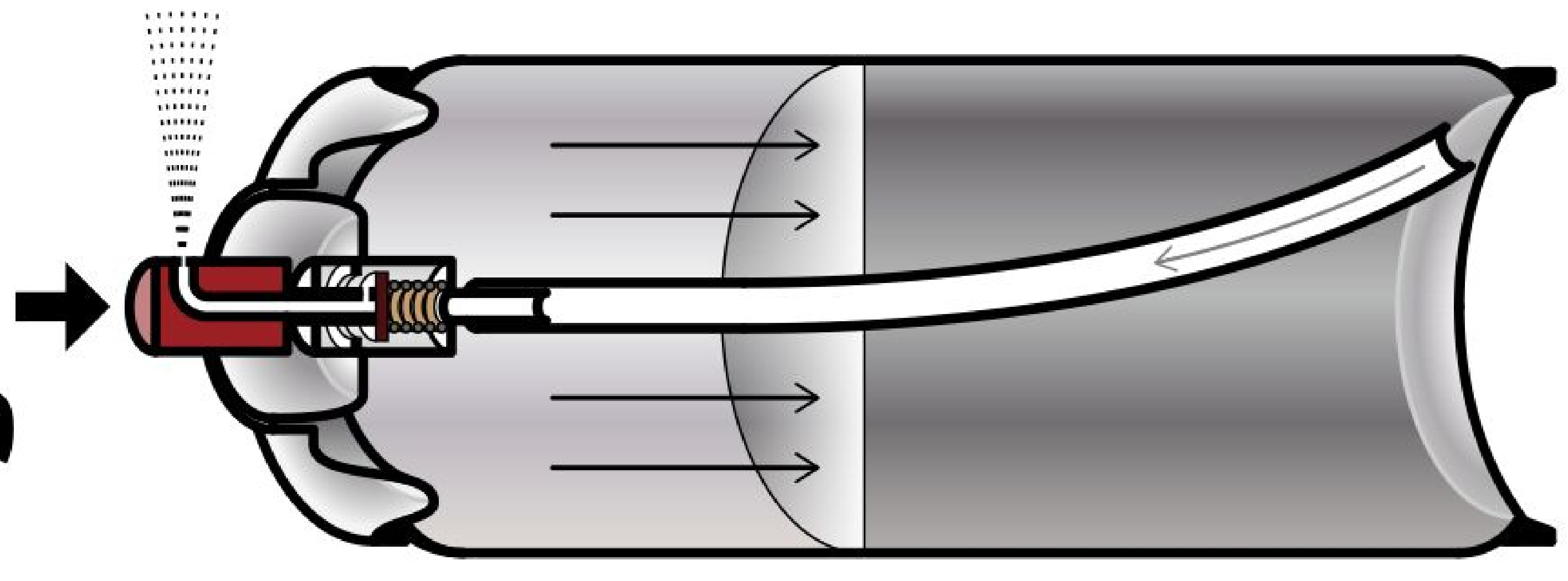


What is an aerosol?

Aerosol is actually a very general term for a mist of solid or liquid particles that are dispersed in a gas. As well as the deodorant that comes out of a can, there are plenty of other aerosols we encounter in our daily lives. Steam from a kettle is an aerosol because it contains droplets of water vapour. The smoke from candles is another kind of aerosol as the melted wax and soot particles are suspended within the surrounding air.

Compressed gas

The other common method of creating an aerosol spray is the compressed gas system. This system begins in a similar manner to the liquefied gas system as the liquid product gets poured into the can. It gets sealed shut and the gaseous propellant is pumped into it via the nozzle. As with the liquefied gas system, the propellant is highly pressurised, but here it doesn't mix with the liquid product. It sits on top of the product instead, squashing it to the bottom of the can and up a tube that ends just below the nozzle. When the nozzle is depressed the airtight seal is opened and the downward force of the propellant pushes the product out of the gap. The small nozzle atomises the liquid product, breaking it up into tiny droplets that form a misty spray.



The compressed air system pushes down on the product without mixing

© Thinkstock; Dreamstime

The science of your skin

Lifting the lid on the body's largest and most sensitive organ

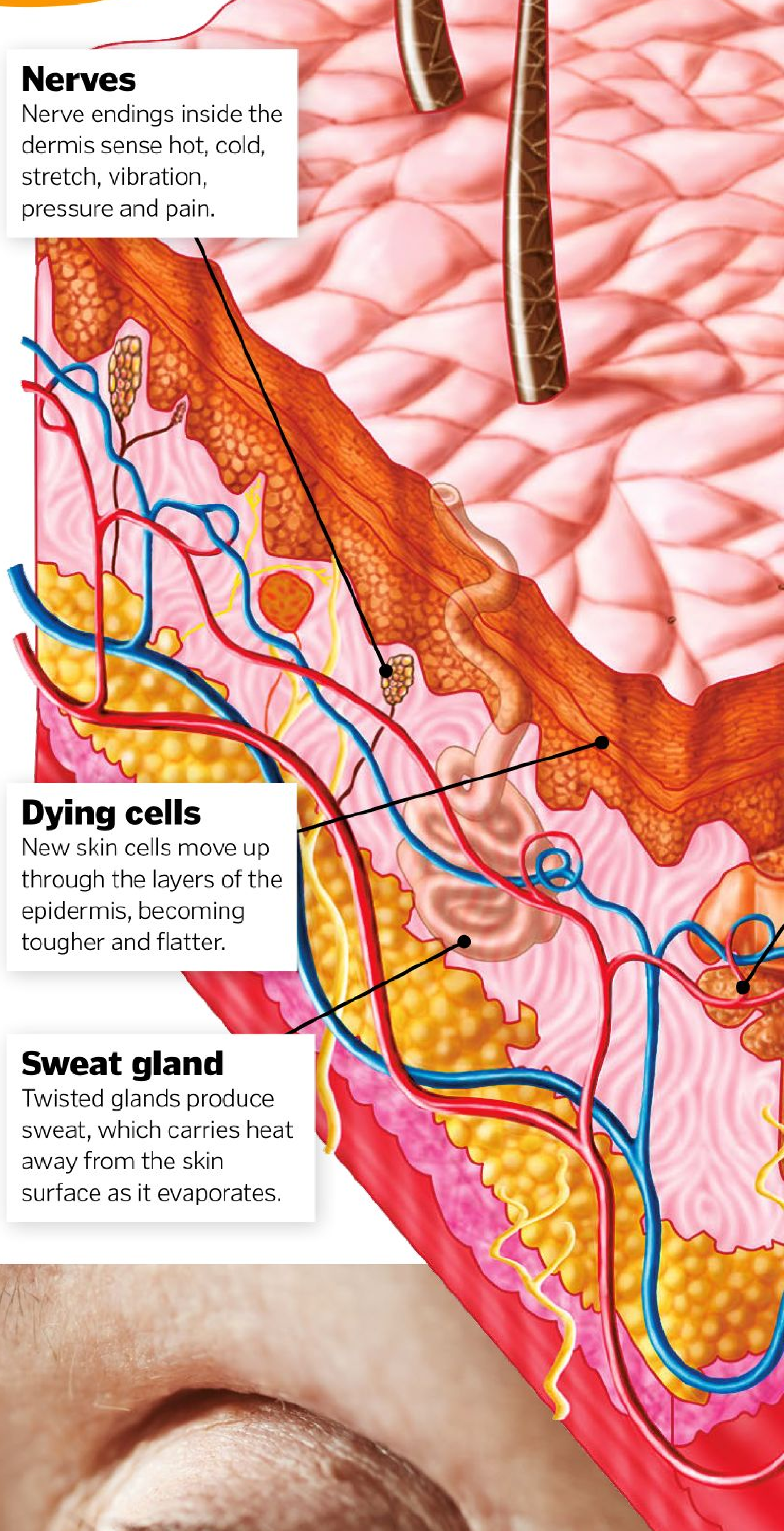
Cells called fibroblasts make the elastic tissue that supports our skin

Weighing in at 2.7 kilograms, your skin is by far the largest organ in, or rather on, your body. Wrapped around you from head to toe, it provides a waterproof barrier that separates your tissues from the outside world. Skin keeps moisture in, blocks out the light, stores fat, senses touch, regulates temperature and shields you against infection. To do all this it has three separate layers, each packed with a different set of specialist cells.

The outermost layer of the skin is the epidermis. It contains four or five layers of skin cells, which come from cube-shaped stem cells deep under the surface. These stem cells make enough new skin cells to completely replace your skin every four weeks. The skin cells themselves are called keratinocytes, because they make the protein keratin. This is the same tough fibre that makes hair and nails. As new keratinocytes appear, they push the old ones upwards and, as the cells get closer to the surface, they become flatter and tougher. The cells die as they reach the very outer layer, forming a hard and water-resistant barrier.

Collagen fibres connect the epidermis to the next layer of skin via a series of finger-shaped folds. This layer, called the dermis, contains blood and lymphatic vessels, nerves, hair follicles and sweat glands. These structures all sit in a layer of flexible fibres, which are made by specialised cells called fibroblasts. The fibres – elastin and collagen – give skin its strength and ability to stretch.

The very bottom layer of skin is the hypodermis, and it links the skin to the inside of the body, connecting it up with muscle, bone and tissue. Here, cells called adipocytes store excess energy as fat, providing a layer of insulation and cushioning against impacts.



Nerves
Nerve endings inside the dermis sense hot, cold, stretch, vibration, pressure and pain.

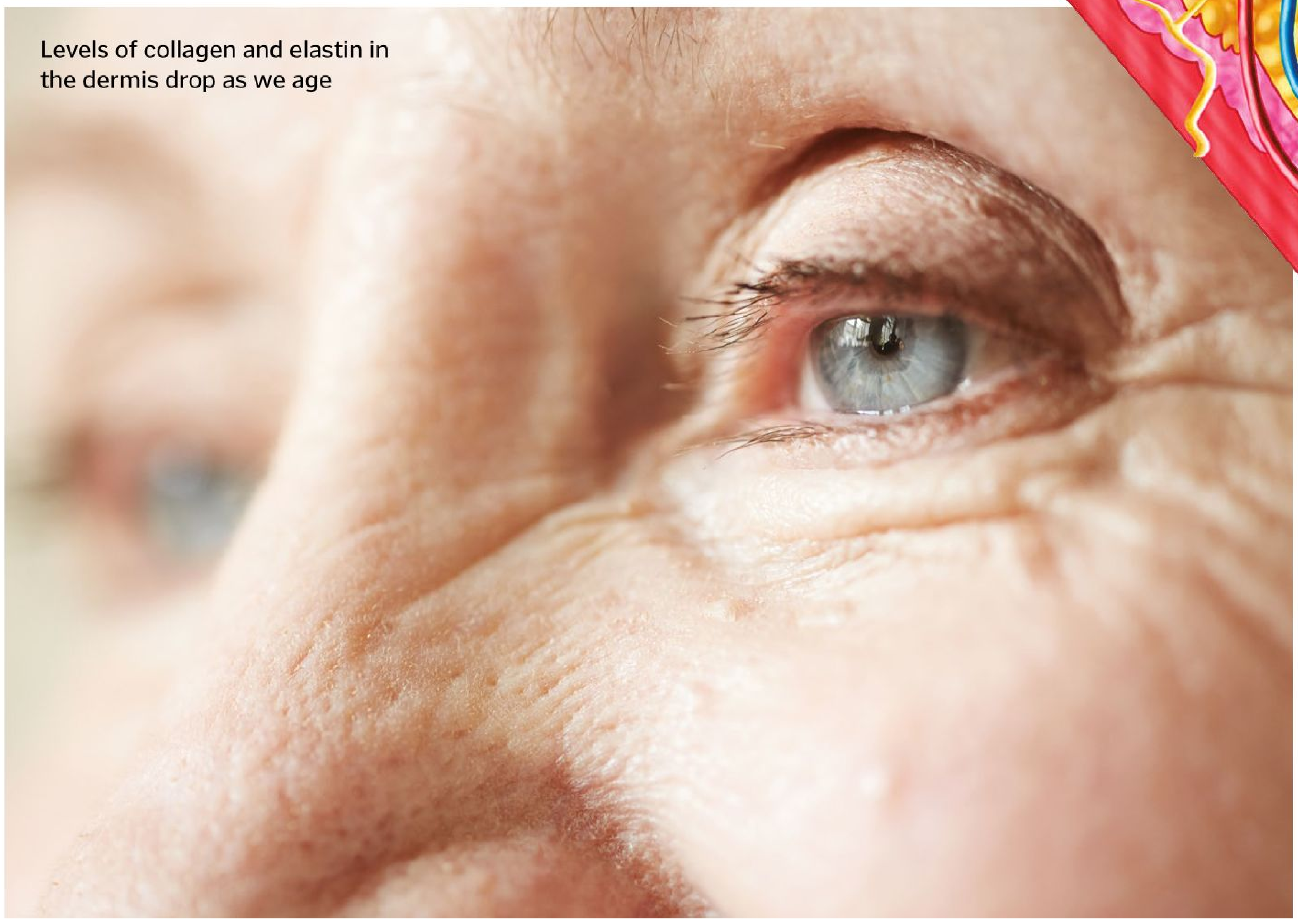
Dying cells
New skin cells move up through the layers of the epidermis, becoming tougher and flatter.

Sweat gland
Twisted glands produce sweat, which carries heat away from the skin surface as it evaporates.

Types of skin

Your skin might be one organ, but it's not the same all over your body; different zones vary in thickness, oiliness, sweatiness and hairiness. The palms of your hands and the soles of your feet have the thickest skin, with an extra layer of cells in the epidermis. They have fat pads under the surface and, though they don't make hair or sebum, they produce lots of sweat. Your armpits, in contrast, are very hairy and produce lots of oil, contributing to body odour. They also have a higher pH than the rest of the skin, making it much easier for bacteria to grow. The most delicate skin on your body is on your eyelids. At just 0.04mm thick it is 40-times thinner than the skin on the soles of your feet.

The skin on the palm of your hand has extra layers of cells and fat

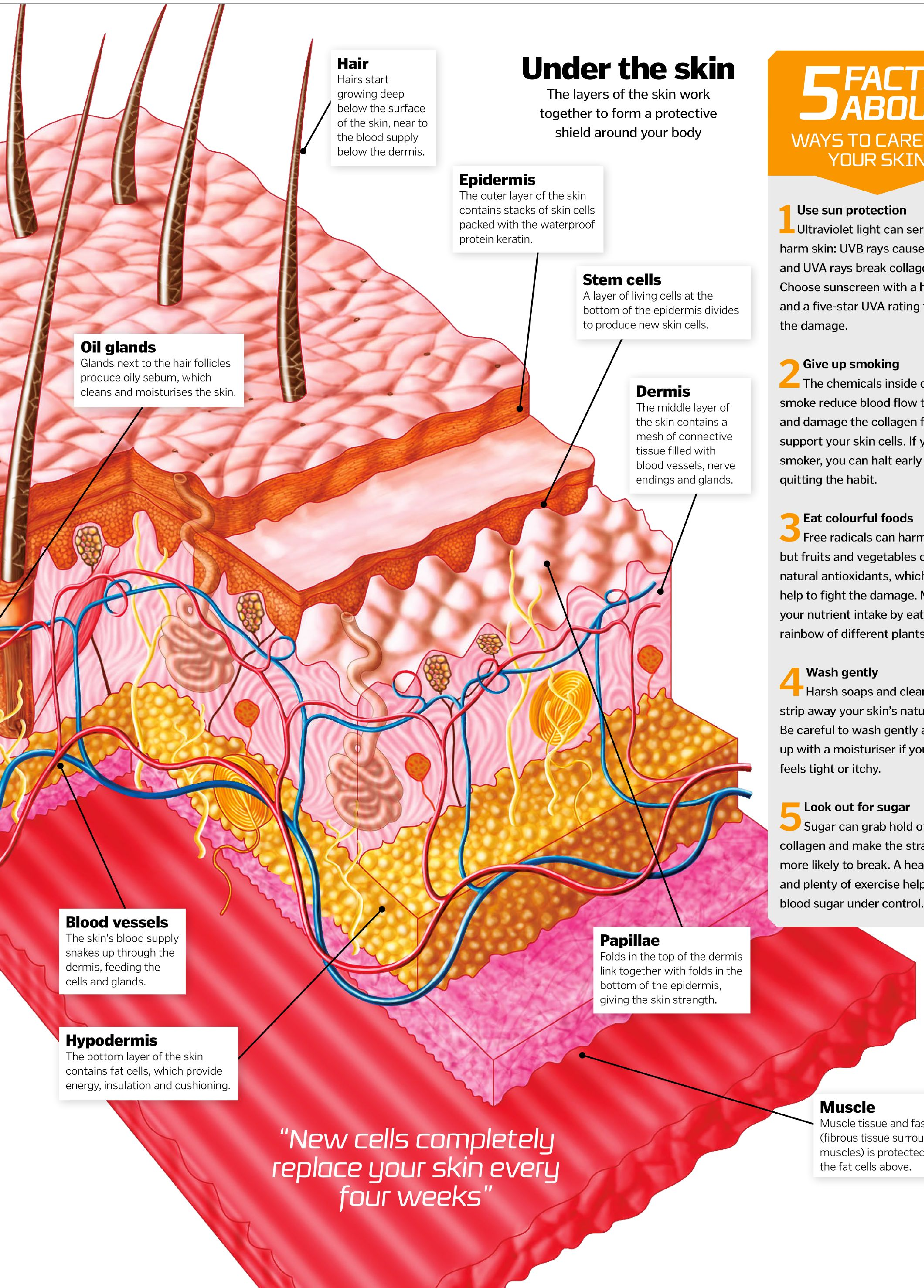


Levels of collagen and elastin in the dermis drop as we age

DID YOU KNOW? *30,000 dead cells flake away from your skin every minute. That's more than 43 million every day!*

Under the skin

The layers of the skin work together to form a protective shield around your body



Hair
Hairs start growing deep below the surface of the skin, near to the blood supply below the dermis.

Epidermis
The outer layer of the skin contains stacks of skin cells packed with the waterproof protein keratin.

Stem cells
A layer of living cells at the bottom of the epidermis divides to produce new skin cells.

Oil glands
Glands next to the hair follicles produce oily sebum, which cleans and moisturises the skin.

Dermis
The middle layer of the skin contains a mesh of connective tissue filled with blood vessels, nerve endings and glands.

Blood vessels
The skin's blood supply snakes up through the dermis, feeding the cells and glands.

Papillae
Folds in the top of the dermis link together with folds in the bottom of the epidermis, giving the skin strength.

Hypodermis
The bottom layer of the skin contains fat cells, which provide energy, insulation and cushioning.

Muscle
Muscle tissue and fascia (fibrous tissue surrounding muscles) is protected by the fat cells above.

> *"New cells completely replace your skin every four weeks"*

5 FACTS ABOUT

WAYS TO CARE FOR YOUR SKIN

1 Use sun protection
Ultraviolet light can seriously harm skin: UVB rays cause sunburn and UVA rays break collagen fibres. Choose sunscreen with a high SPF and a five-star UVA rating to slow the damage.

2 Give up smoking
The chemicals inside cigarette smoke reduce blood flow to the skin and damage the collagen fibres that support your skin cells. If you are a smoker, you can halt early ageing by quitting the habit.

3 Eat colourful foods
Free radicals can harm the skin, but fruits and vegetables contain natural antioxidants, which may help to fight the damage. Maximise your nutrient intake by eating a rainbow of different plants.

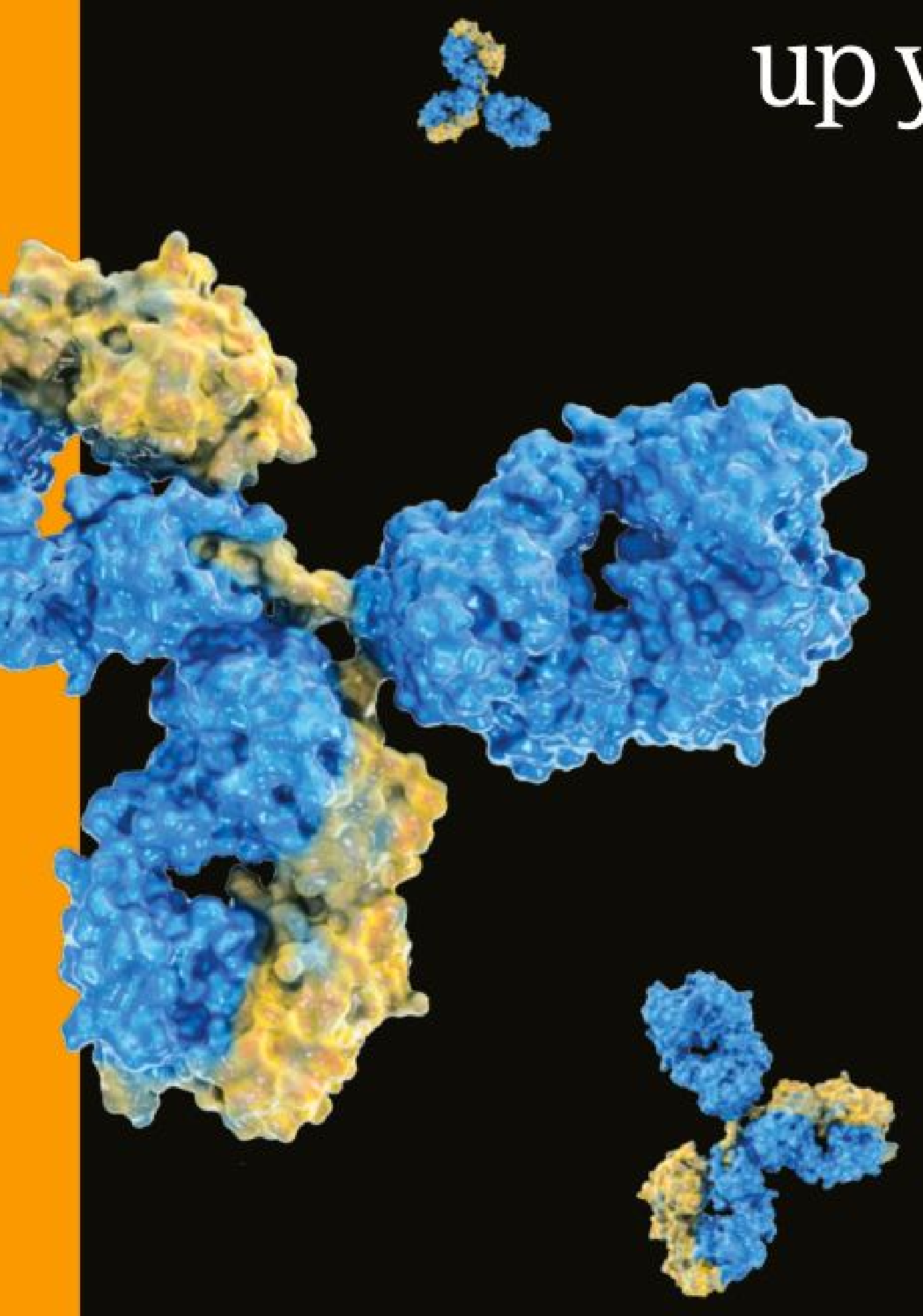
4 Wash gently
Harsh soaps and cleansers can strip away your skin's natural oils. Be careful to wash gently and top up with a moisturiser if your skin feels tight or itchy.

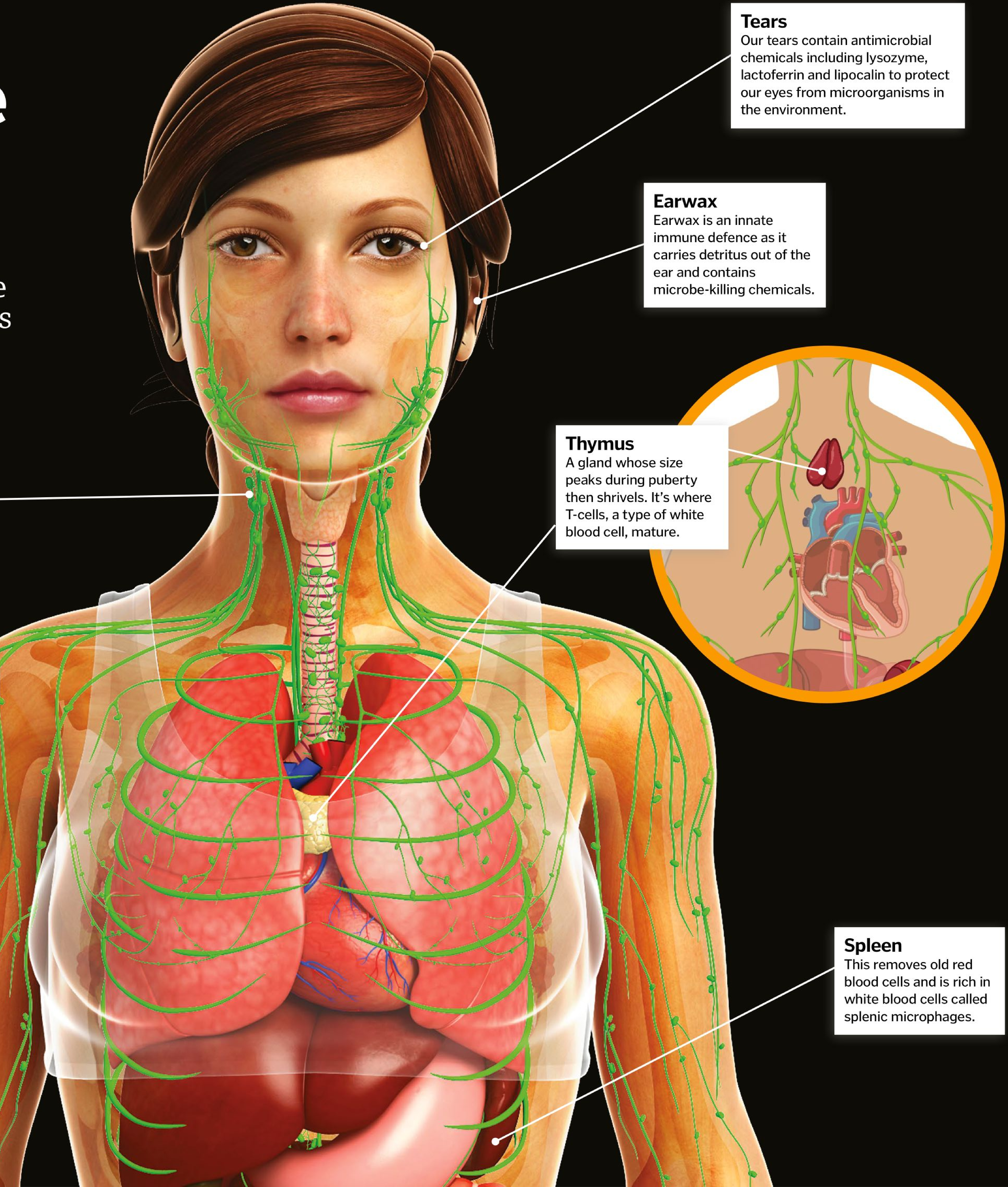
5 Look out for sugar
Sugar can grab hold of skin collagen and make the strands more likely to break. A healthy diet and plenty of exercise helps to keep blood sugar under control.

© Getty

Your immune system

Discover some of the different organs and components that make up your body's defences





Tears
Our tears contain antimicrobial chemicals including lysozyme, lactoferrin and lipocalin to protect our eyes from microorganisms in the environment.

Earwax
Earwax is an innate immune defence as it carries detritus out of the ear and contains microbe-killing chemicals.

Lymph nodes
This is where special white blood cells can be presented with foreign material like bacteria and set off to kill it.

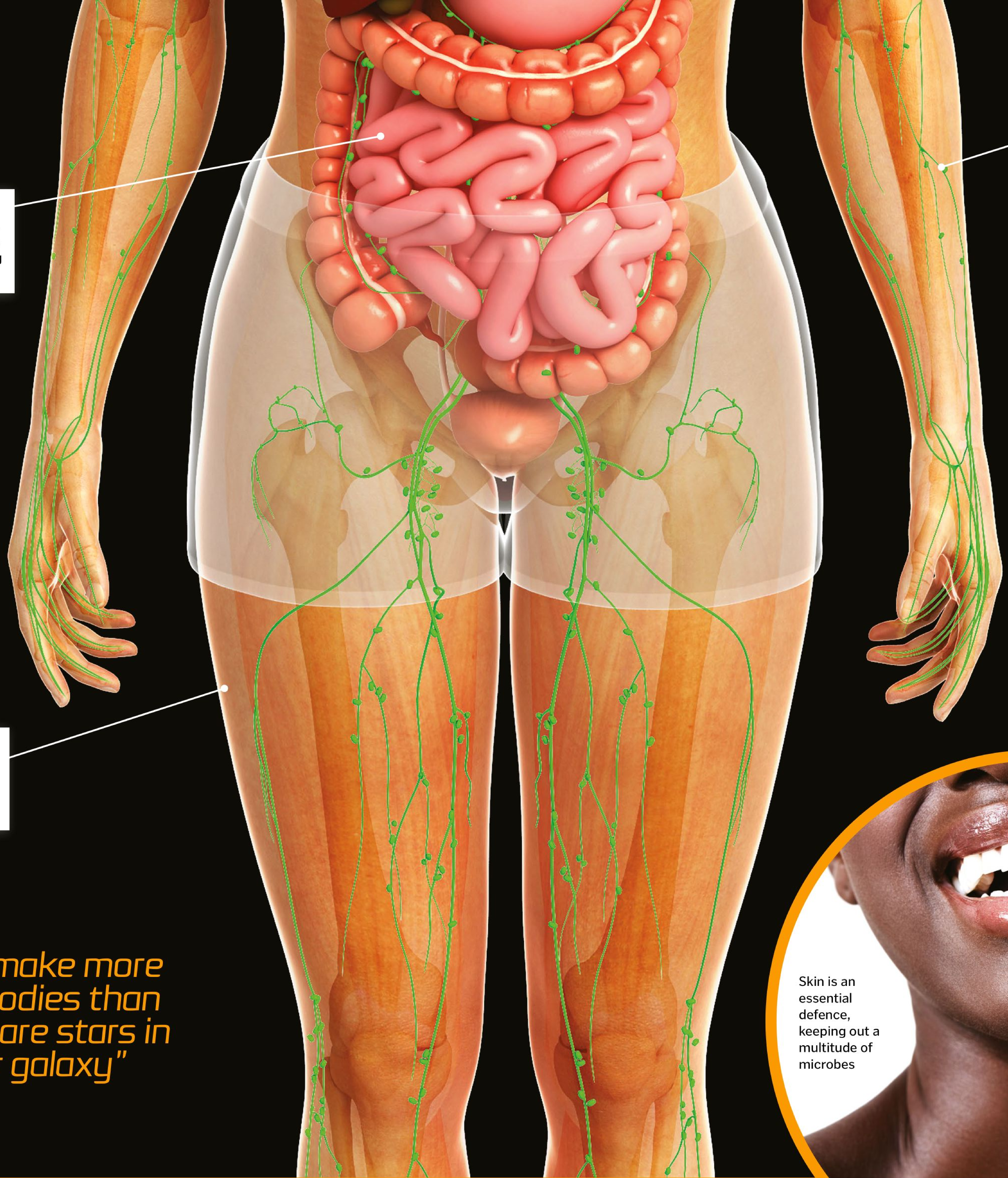
Thymus
A gland whose size peaks during puberty then shrivels. It's where T-cells, a type of white blood cell, mature.

Spleen
This removes old red blood cells and is rich in white blood cells called splenic microphages.

URGENT
HUMAN
ORGANS

The immune system is critical to the success or failure of organ transplants

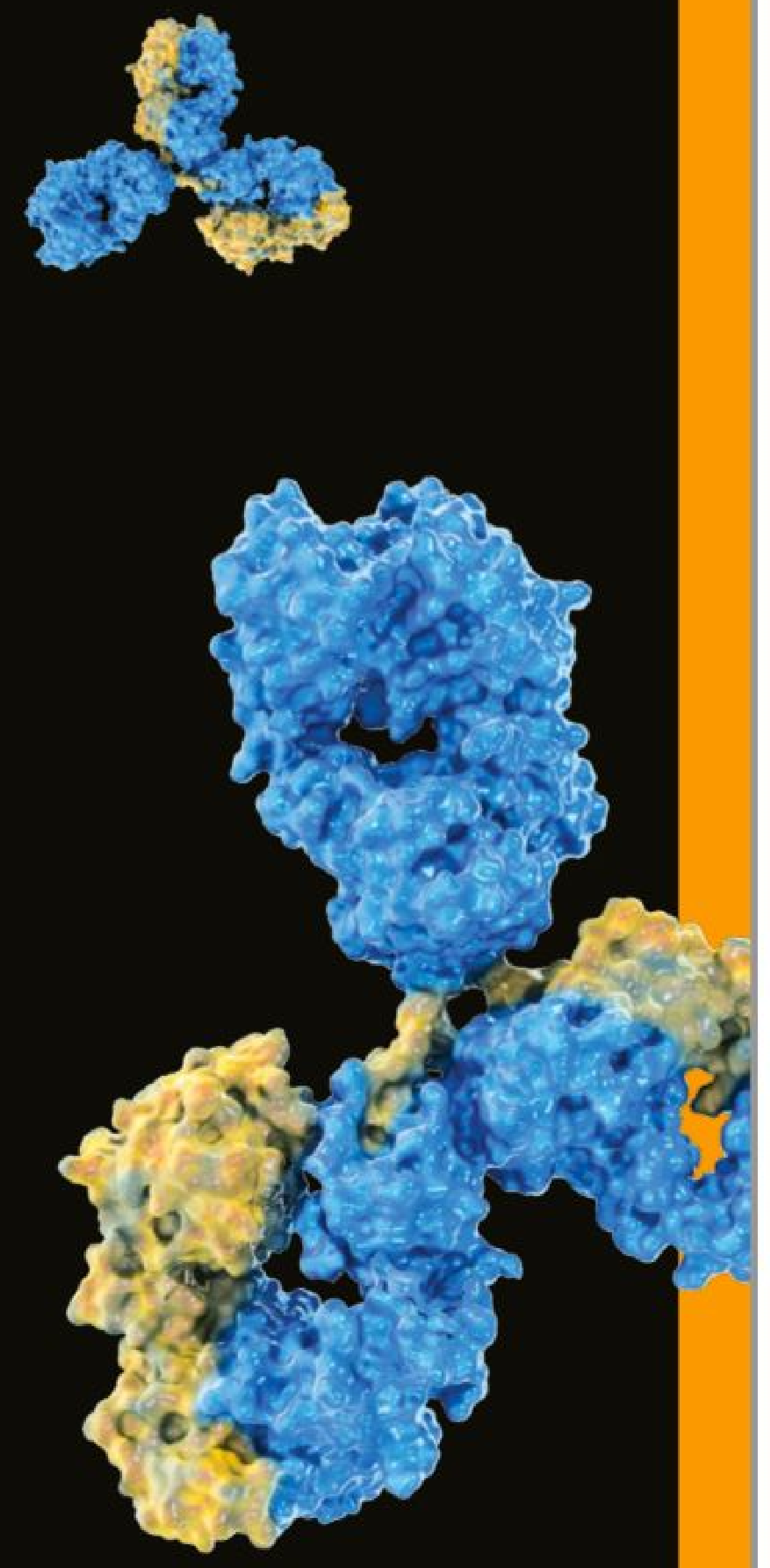
DID YOU KNOW? *Human skin has been used to make wallets and book covers, and laid flat it'd make a sizeable 2m² rug*



Lymphatic vessels
An unidirectional transport network that's a key way for white blood cells to travel the body.

Intestine
Contains Peyer's patches, tissue that can act like an alert system for detecting intruders in the gut.

Skin
Skin is an essential part of the immune system, keeping potentially dangerous microbes out.



Skin is an essential defence, keeping out a multitude of microbes

> "We make more antibodies than there are stars in our galaxy"

Inside your foot

One of the first things we learn to do is walk, but how exactly do we move from heel to toe?

With every step we take, a set of biological cogs are set in motion, enabling us to get from A to B.

The action of walking may seem pretty straightforward, but actually our feet are made up of a complex and unique arrangement of bones, tendons and ligaments.

Tendons are the rigid and fibrous tissues that attach muscles to a bone. In the case of moving the foot, the main tendon engaged is the Achilles tendon, which connects your calf muscle to your hindfoot bone, called the calcaneus.

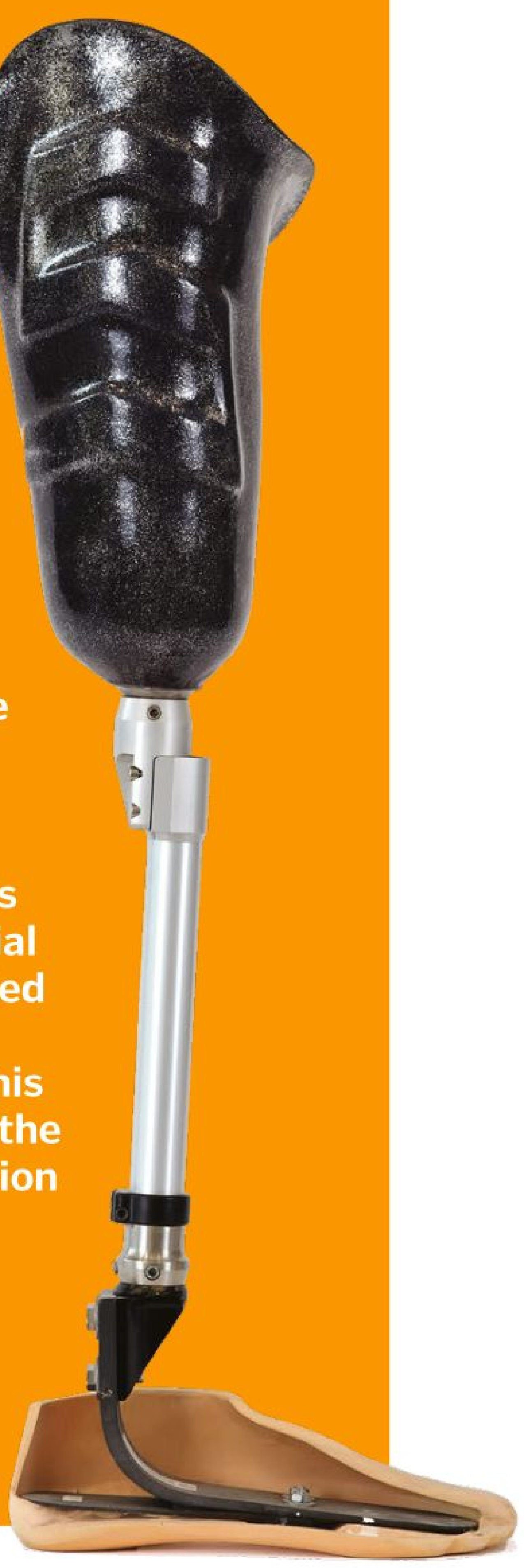
Ligaments are bands of elastic connective tissue that bridge the gap between bones. In order for the muscles connecting the foot to contract and relax – the basis of movement – they require stimulation from nerves that feed into the foot, like the tibial nerve.

A type of connective fibrous tissue, known as the plantar fascia, is responsible for putting the spring in your step. Spanning the length of your foot, this tissue acts as a springboard. As we lift our foot at the beginning of a step, the tissue becomes taut due to our toes lifting upwards. As the foot is returned to the ground, the tension in the tissue increases further, storing energy like a spring. That energy is released in the next step, giving our footsteps their bounce.

Each foot consists of 26 bones

Artificial limb

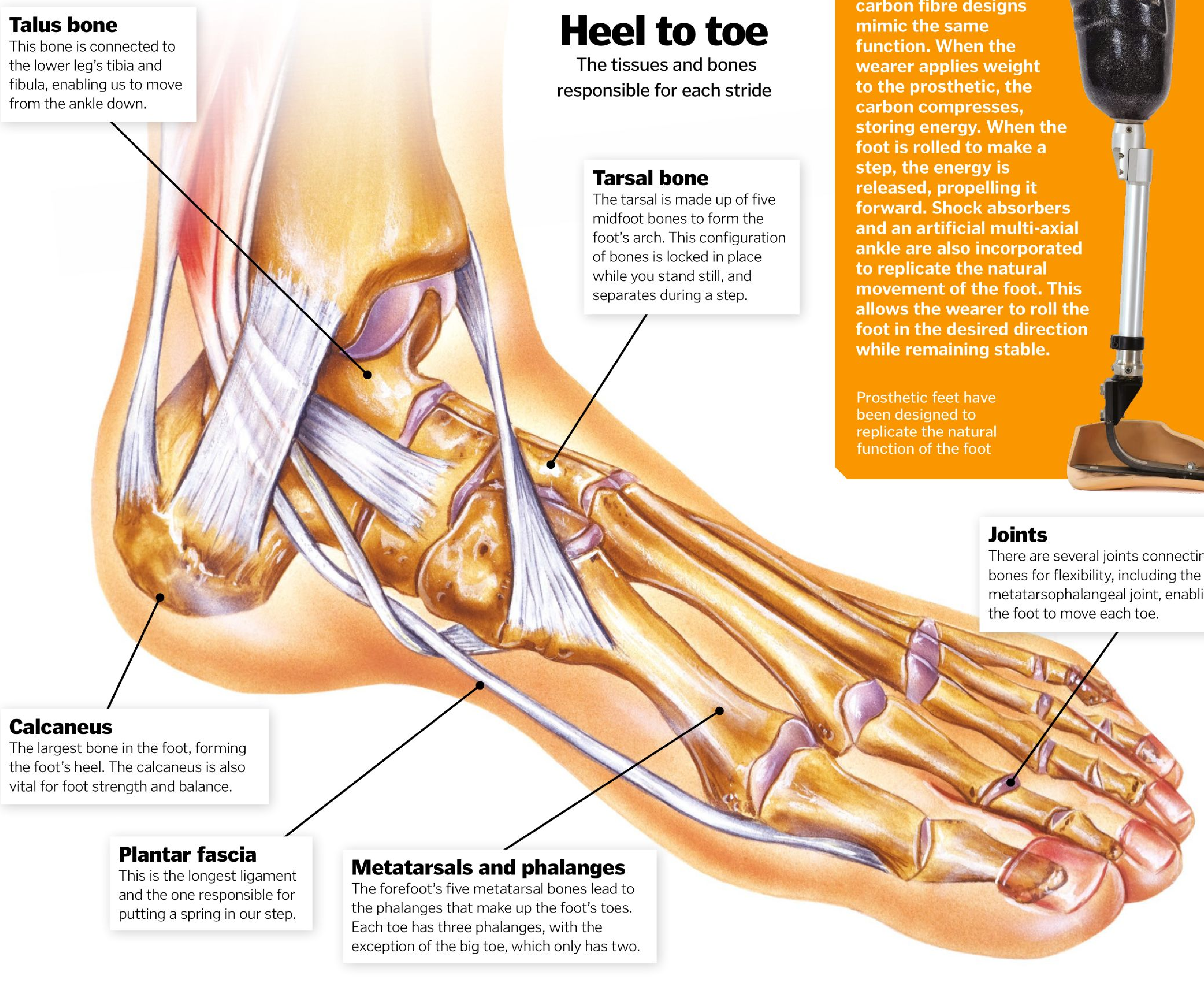
In recreating the human foot, some prosthetic feet have been designed to replicate its natural physics. As the plantar fascia acts as the energy store for a biological foot, many prosthetic carbon fibre designs mimic the same function. When the wearer applies weight to the prosthetic, the carbon compresses, storing energy. When the foot is rolled to make a step, the energy is released, propelling it forward. Shock absorbers and an artificial multi-axial ankle are also incorporated to replicate the natural movement of the foot. This allows the wearer to roll the foot in the desired direction while remaining stable.



Prosthetic feet have been designed to replicate the natural function of the foot

Heel to toe

The tissues and bones responsible for each stride



Talus bone
This bone is connected to the lower leg's tibia and fibula, enabling us to move from the ankle down.

Tarsal bone
The tarsal is made up of five midfoot bones to form the foot's arch. This configuration of bones is locked in place while you stand still, and separates during a step.

Joints
There are several joints connecting bones for flexibility, including the metatarsophalangeal joint, enabling the foot to move each toe.

Calcaneus
The largest bone in the foot, forming the foot's heel. The calcaneus is also vital for foot strength and balance.

Plantar fascia
This is the longest ligament and the one responsible for putting a spring in our step.

Metatarsals and phalanges
The forefoot's five metatarsal bones lead to the phalanges that make up the foot's toes. Each toe has three phalanges, with the exception of the big toe, which only has two.

© Getty

Inside your hand

The evolution of this dextrous appendage has been one of the keys to human success

For most of us, hands are pieces of equipment taken for granted. We grab, manoeuvre, tap, gesture and touch without thinking about the astounding complexity and accuracy of the movements. Fold down just one finger and everyday tasks become much harder, because over human history the hand has become highly specialised.

Standing on two legs freed up the arms of our ancestors for a greater range of uses. It's believed that the tool use of early hominids began the transition from an ape-like appendage to the modern hand; those with hands better suited to gripping stones were able to smash animal bones and access the nutritious marrow inside.

Other primates like orangutans have hands similar in shape to ours, but the human hand is in a league of its own in terms of dexterity. While our primate relatives have short thumbs and long fingers for grabbing and swinging from branches, humans have evolved shorter fingers and considerably longer and more mobile thumbs. This anatomical change has resulted in two fundamental types of human grip: the power grip and the precision grip. Early in human history these grips would have been useful primarily for throwing and clubbing, but today they allow us to master everything from the pole vault to intricate needlework.

Like other apes, humans have flattened fingernails rather than claws. Claws provide grip for climbing and traction while running, but they impede fine movements. As well as allowing careful manipulation of objects, primate fingernails are still useful for gripping, pinching and scratching.

Thumbs up

Much of the precision and versatility of our hands is thanks to our opposable thumbs, a rarity in the animal kingdom. Humans can move their long thumbs in multiple directions and touch them to every other finger on the hand, producing a firm grip and the ability to handle objects delicately.

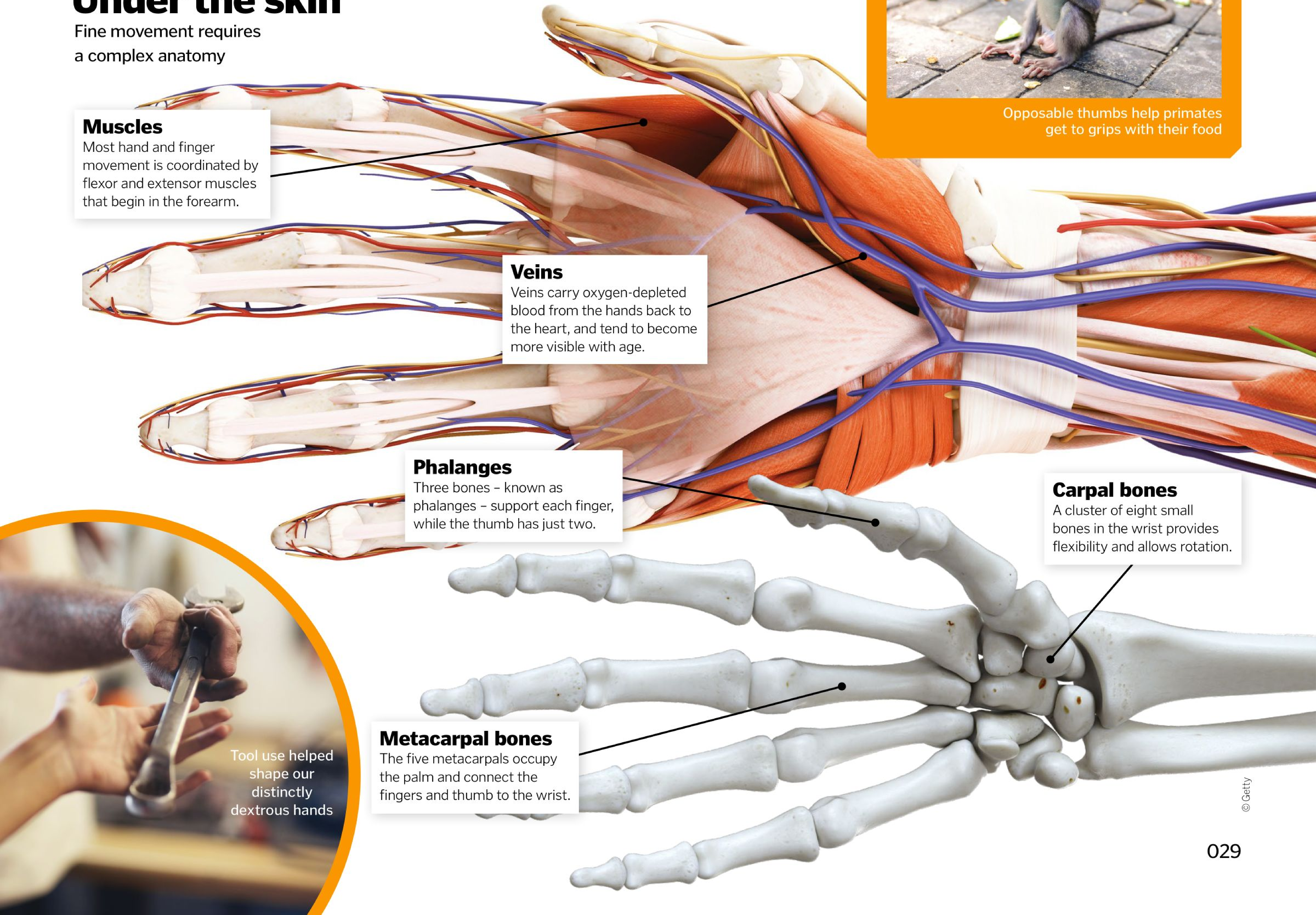
While humans are the most mobile, we're not the only ones with opposable thumbs. Great apes have both opposable thumbs and opposable big toes, useful for gathering food and building nests. Lesser apes and Old World monkeys also have opposable thumbs. They keep them out of the way when they're swinging through the trees, but employ them for tasks like picking fruit and grooming.

Other tree-dwelling species like koalas and even some species of arboreal frog have mobile thumbs. Opossums have them on their hind legs, working with their prehensile tails to provide stability.

Opposable thumbs help primates get to grips with their food

Under the skin

Fine movement requires a complex anatomy



Muscles
Most hand and finger movement is coordinated by flexor and extensor muscles that begin in the forearm.

Veins
Veins carry oxygen-depleted blood from the hands back to the heart, and tend to become more visible with age.

Phalanges
Three bones – known as phalanges – support each finger, while the thumb has just two.

Carpal bones
A cluster of eight small bones in the wrist provides flexibility and allows rotation.

Metacarpal bones
The five metacarpals occupy the palm and connect the fingers and thumb to the wrist.

Tool use helped shape our distinctly dextrous hands

© Getty

The science of Christmas dinner

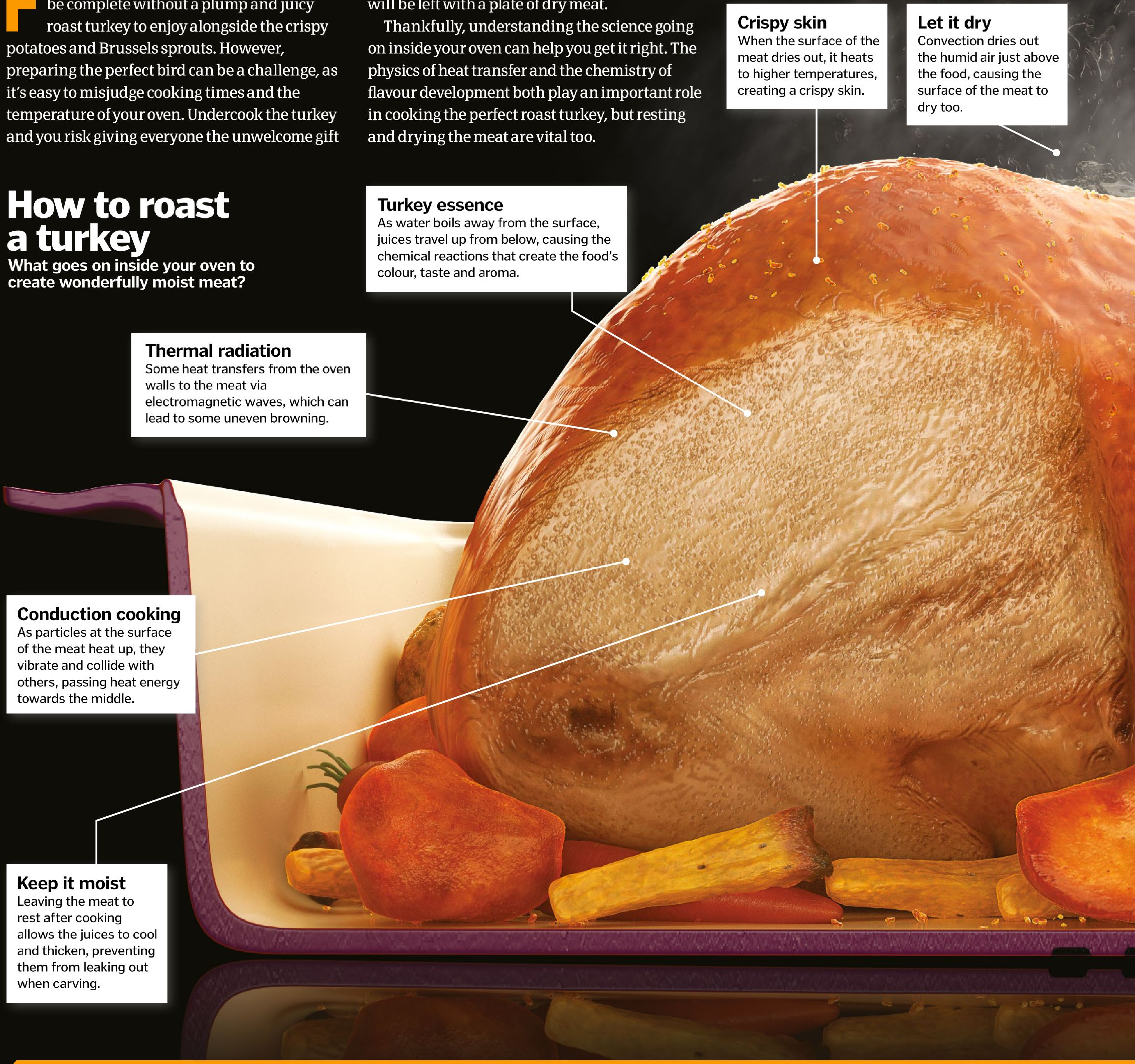
Learn the physics and chemistry that will help you cook the perfect festive feast

For most Brits, Christmas dinner would not be complete without a plump and juicy roast turkey to enjoy alongside the crispy potatoes and Brussels sprouts. However, preparing the perfect bird can be a challenge, as it's easy to misjudge cooking times and the temperature of your oven. Undercook the turkey and you risk giving everyone the unwelcome gift of food poisoning, yet overcook it and your guests will be left with a plate of dry meat.

Thankfully, understanding the science going on inside your oven can help you get it right. The physics of heat transfer and the chemistry of flavour development both play an important role in cooking the perfect roast turkey, but resting and drying the meat are vital too.

How to roast a turkey

What goes on inside your oven to create wonderfully moist meat?



Crispy skin
When the surface of the meat dries out, it heats to higher temperatures, creating a crispy skin.

Let it dry
Convection dries out the humid air just above the food, causing the surface of the meat to dry too.

Turkey essence
As water boils away from the surface, juices travel up from below, causing the chemical reactions that create the food's colour, taste and aroma.

Thermal radiation
Some heat transfers from the oven walls to the meat via electromagnetic waves, which can lead to some uneven browning.

Conduction cooking
As particles at the surface of the meat heat up, they vibrate and collide with others, passing heat energy towards the middle.

Keep it moist
Leaving the meat to rest after cooking allows the juices to cool and thicken, preventing them from leaking out when carving.

Christmas cooking science tips

1 Brine the turkey
Before roasting, soak the turkey in salty water for at least 12 hours. The salt will change the protein structure within the turkey's muscle fibres, helping it to retain more moisture while cooking.

2 Start upside down
The turkey breast should be cooked at a lower temperature than the rest of the bird, so place it upside down in the oven for the first hour to shield it from the hotter temperatures at the top.

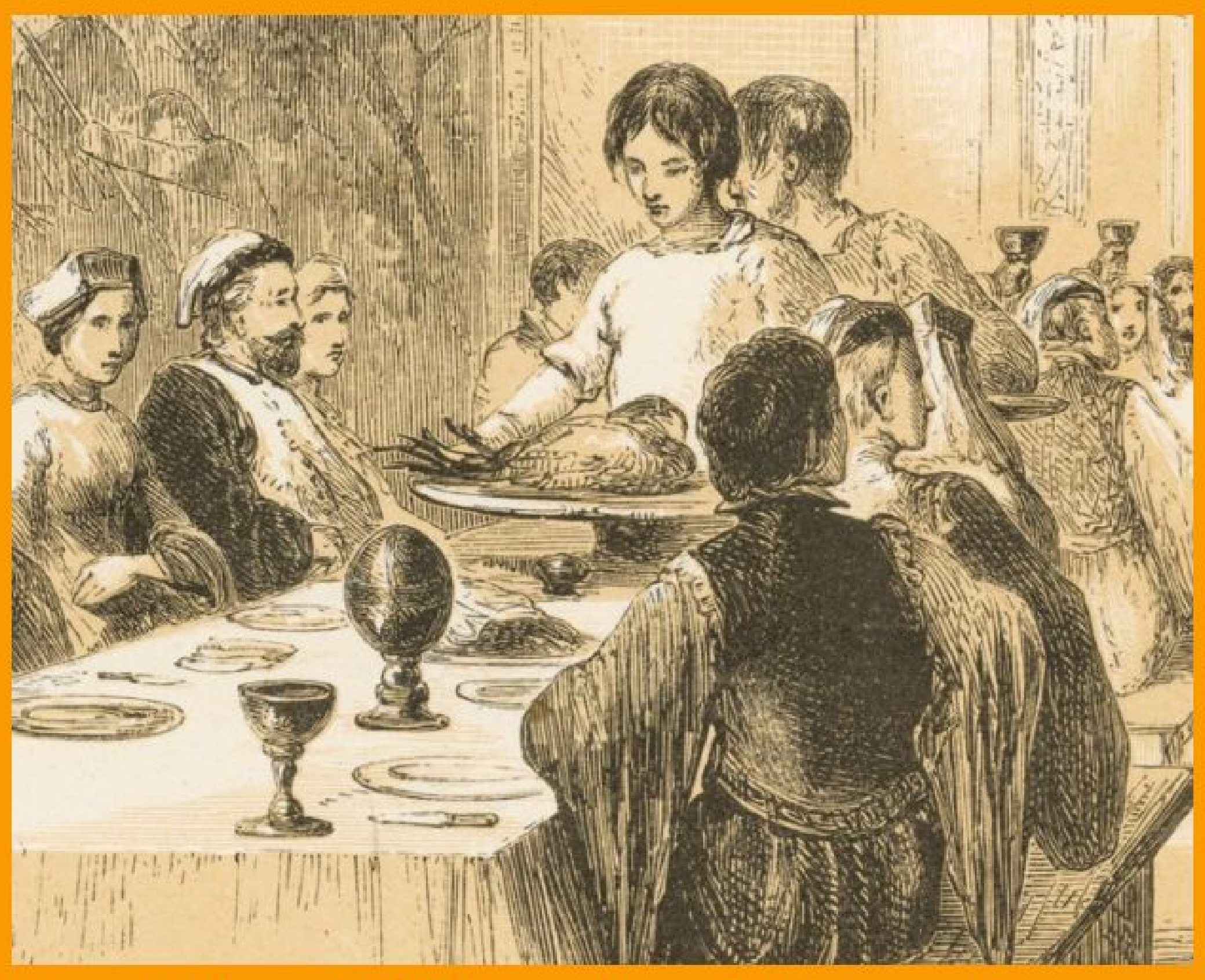
3 Circulate the air
When cooking, place the turkey on a rack that sits inside the roasting tray. This will allow air to circulate evenly around the bird, giving it a crispy brown skin.

DID YOU KNOW? *The average Brit consumes more than 6,000 calories on Christmas day, equivalent to eating 25 chocolate bars*

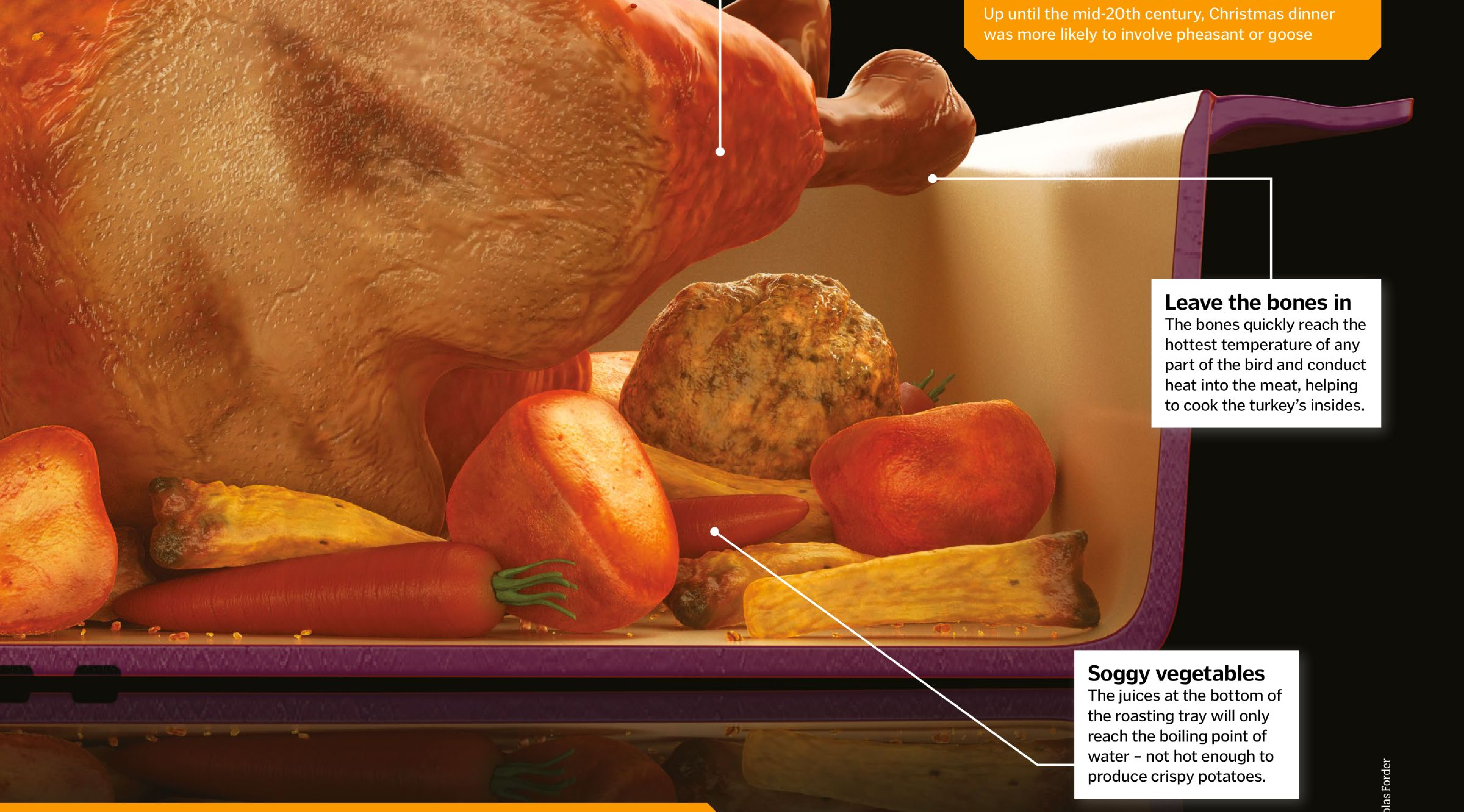
Check the temperature of the turkey before you serve it to make sure it is cooked through

Turkey traditions

No one in Britain had even seen a turkey, let alone eaten one, until the mid-15th century when they were first brought over from the Ottoman Empire, now known as Turkey. King Henry VIII was the first monarch to demand the bird for his Christmas feast, but goose, boar's head or pheasant were traditional Christmas feasts at the time. It wasn't until the 1950s, when turkey was more widely available, that it became a tradition. It was seen as a practical way of feeding a large family and meant that livestock such as cows and chickens could be used for their milk and eggs instead.



Up until the mid-20th century, Christmas dinner was more likely to involve pheasant or goose



Humidity
Water just beneath the surface of the meat begins to boil, creating steam to increase the humidity of the oven.

Convection cooking
Heat energy transferred from the air inside the oven heats the outside of the food.

Added flavour
Heat from the bones also generates chemical reactions in the surrounding meat, giving it more flavour.

Leave the bones in
The bones quickly reach the hottest temperature of any part of the bird and conduct heat into the meat, helping to cook the turkey's insides.

Soggy vegetables
The juices at the bottom of the roasting tray will only reach the boiling point of water – not hot enough to produce crispy potatoes.

4 Check the temperature

When you think the turkey's done, use a meat thermometer to check that the white meat in the breast is at 71 degrees Celsius and the dark meat in the legs and thighs is at 74 degrees Celsius.

5 Cook stuffing separately

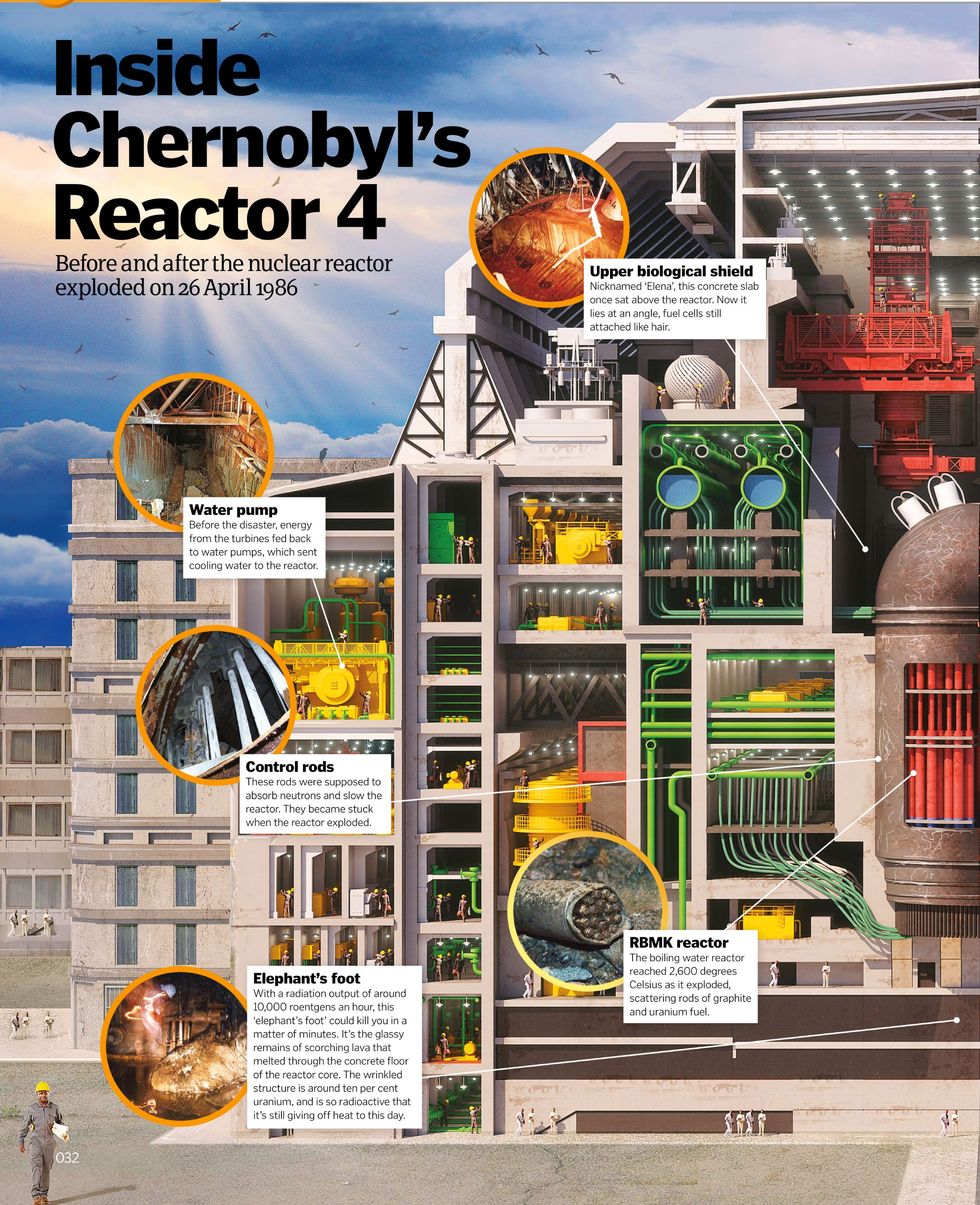
Stuffing must be heated to 74 degrees Celsius due to its egg content, but at that temperature you risk overcooking the turkey. Therefore, it's best to cook it outside of the bird.

> *"Understanding the science going on inside your oven can help you get it right"*

© Alamy; Illustration by Nicholas Forder

Inside Chernobyl's Reactor 4

Before and after the nuclear reactor exploded on 26 April 1986



Upper biological shield
Nicknamed 'Elena', this concrete slab once sat above the reactor. Now it lies at an angle, fuel cells still attached like hair.

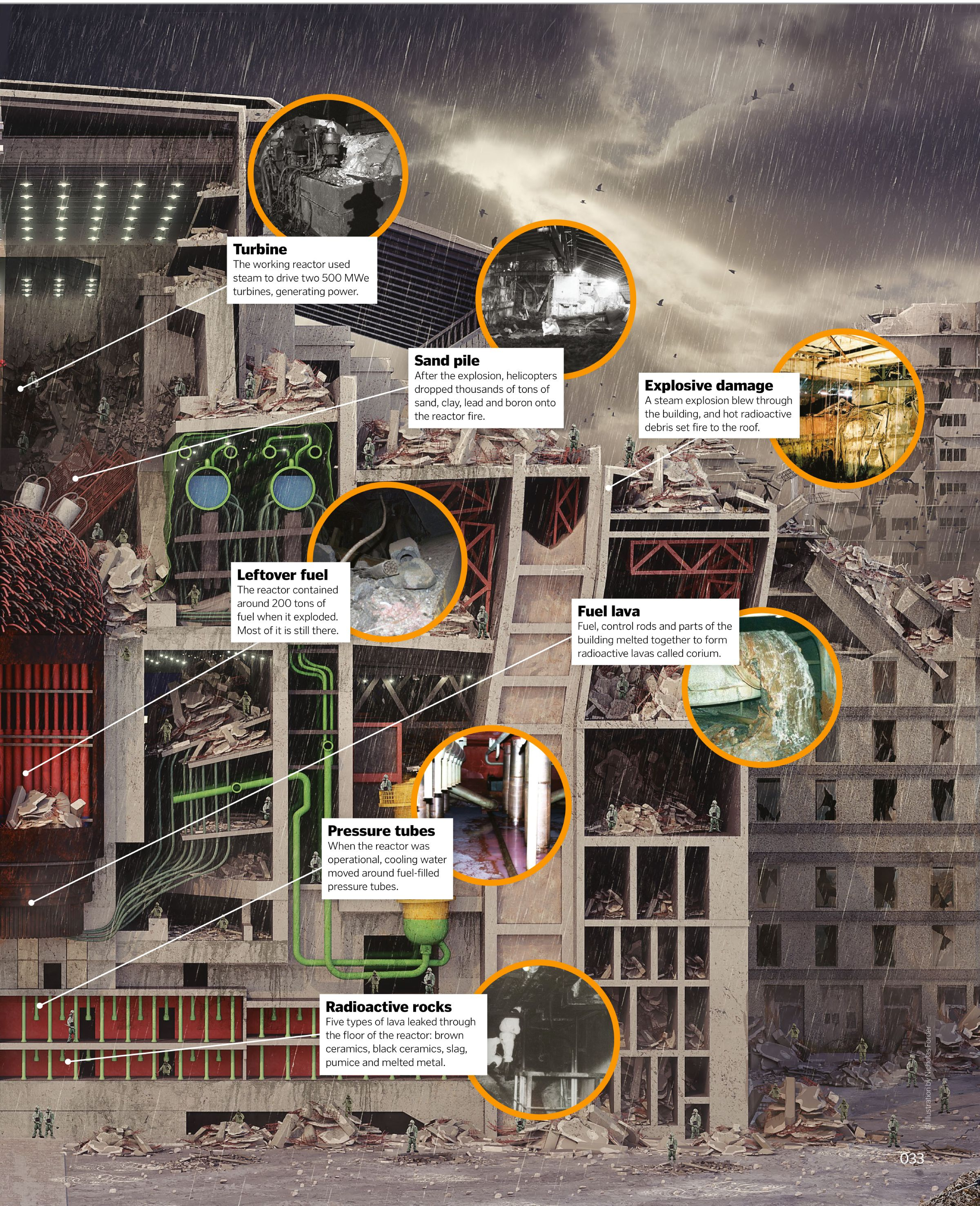
Water pump
Before the disaster, energy from the turbines fed back to water pumps, which sent cooling water to the reactor.

Control rods
These rods were supposed to absorb neutrons and slow the reactor. They became stuck when the reactor exploded.

RBMK reactor
The boiling water reactor reached 2,600 degrees Celsius as it exploded, scattering rods of graphite and uranium fuel.

Elephant's foot
With a radiation output of around 10,000 roentgens an hour, this 'elephant's foot' could kill you in a matter of minutes. It's the glassy remains of scorching lava that melted through the concrete floor of the reactor core. The wrinkled structure is around ten per cent uranium, and is so radioactive that it's still giving off heat to this day.

DID YOU KNOW? *The worst nuclear accident in British history was the three-day Windscale fire at Sellafield in 1957*



Turbine
The working reactor used steam to drive two 500 MWe turbines, generating power.

Sand pile
After the explosion, helicopters dropped thousands of tons of sand, clay, lead and boron onto the reactor fire.

Explosive damage
A steam explosion blew through the building, and hot radioactive debris set fire to the roof.

Leftover fuel
The reactor contained around 200 tons of fuel when it exploded. Most of it is still there.

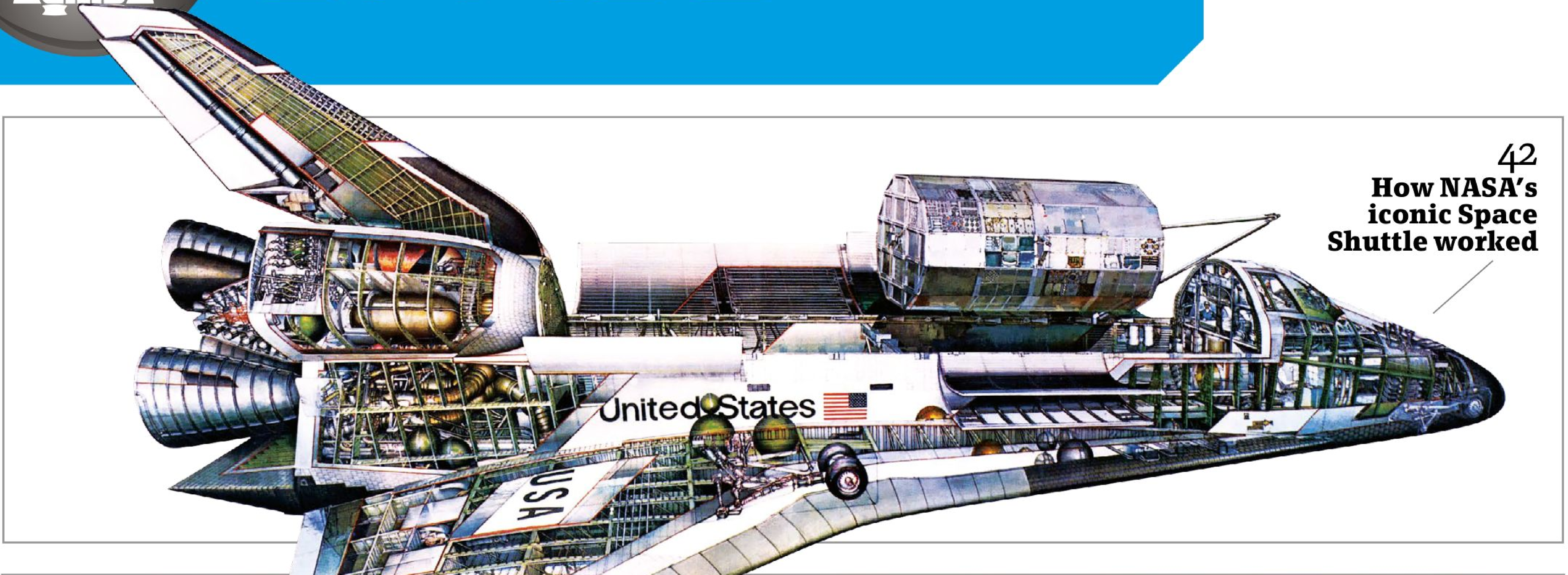
Fuel lava
Fuel, control rods and parts of the building melted together to form radioactive lavas called corium.

Pressure tubes
When the reactor was operational, cooling water moved around fuel-filled pressure tubes.

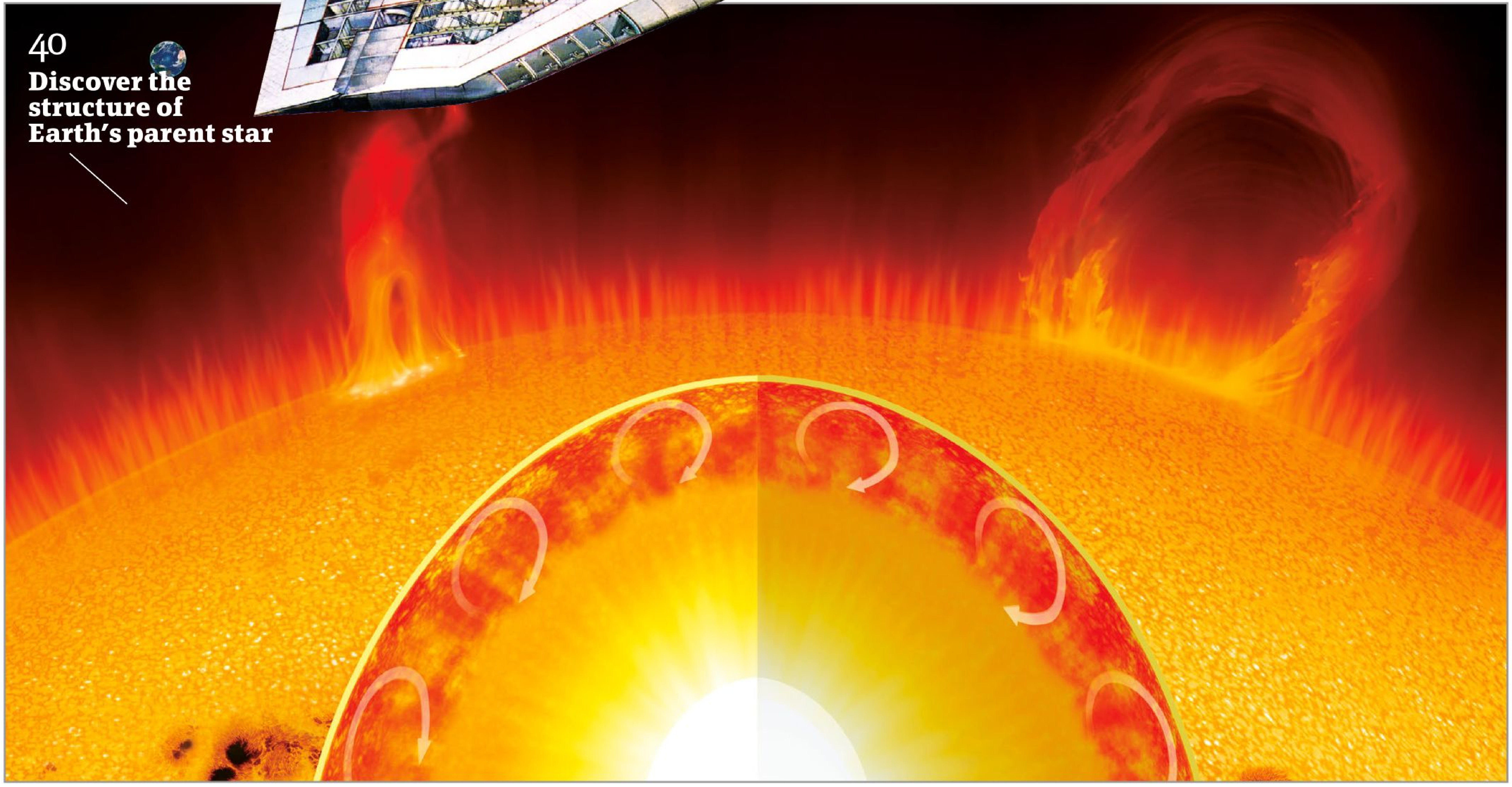
Radioactive rocks
Five types of lava leaked through the floor of the reactor: brown ceramics, black ceramics, slag, pumice and melted metal.

© Illustration by Nicholas Forder

SPACE

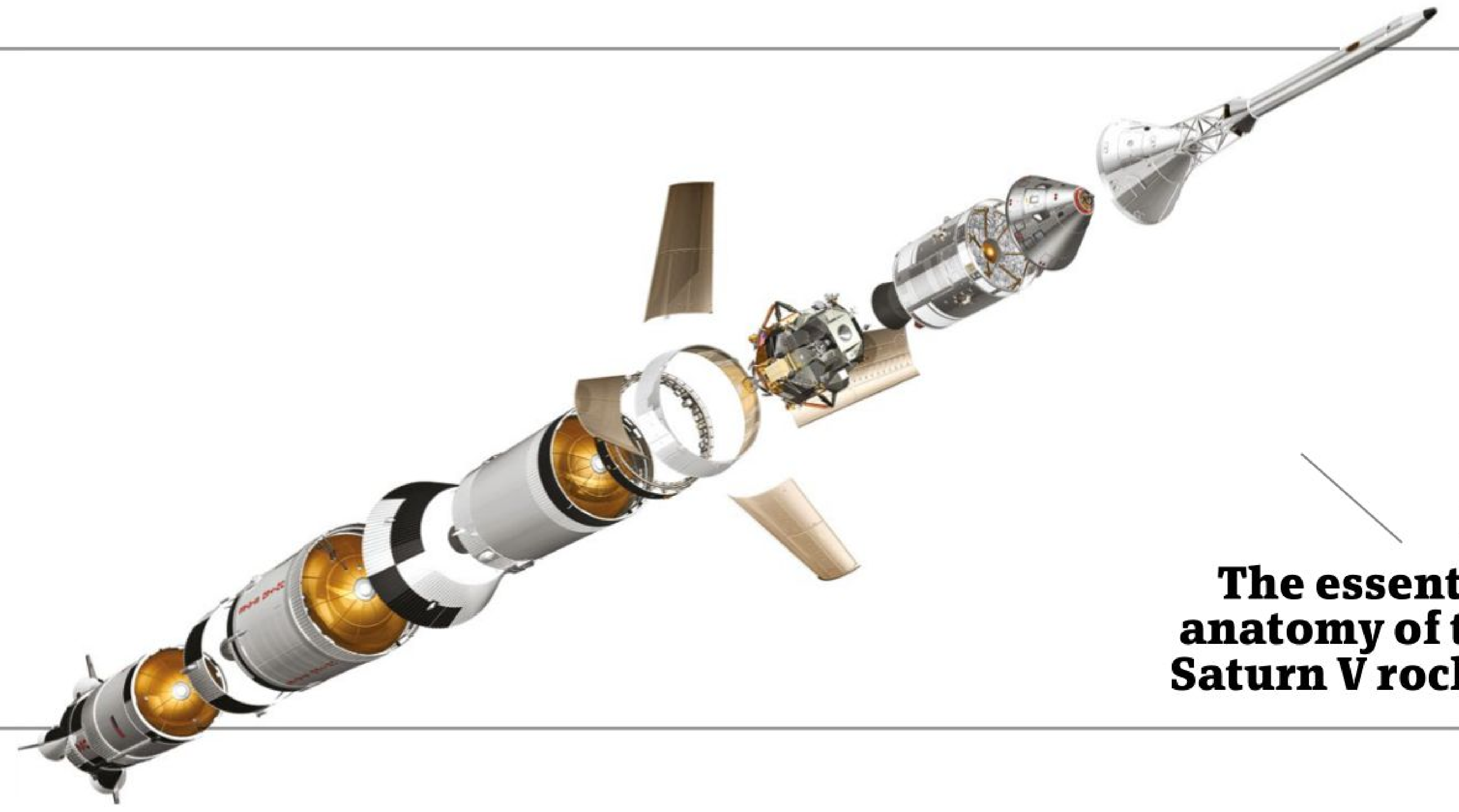


42
How NASA's iconic Space Shuttle worked

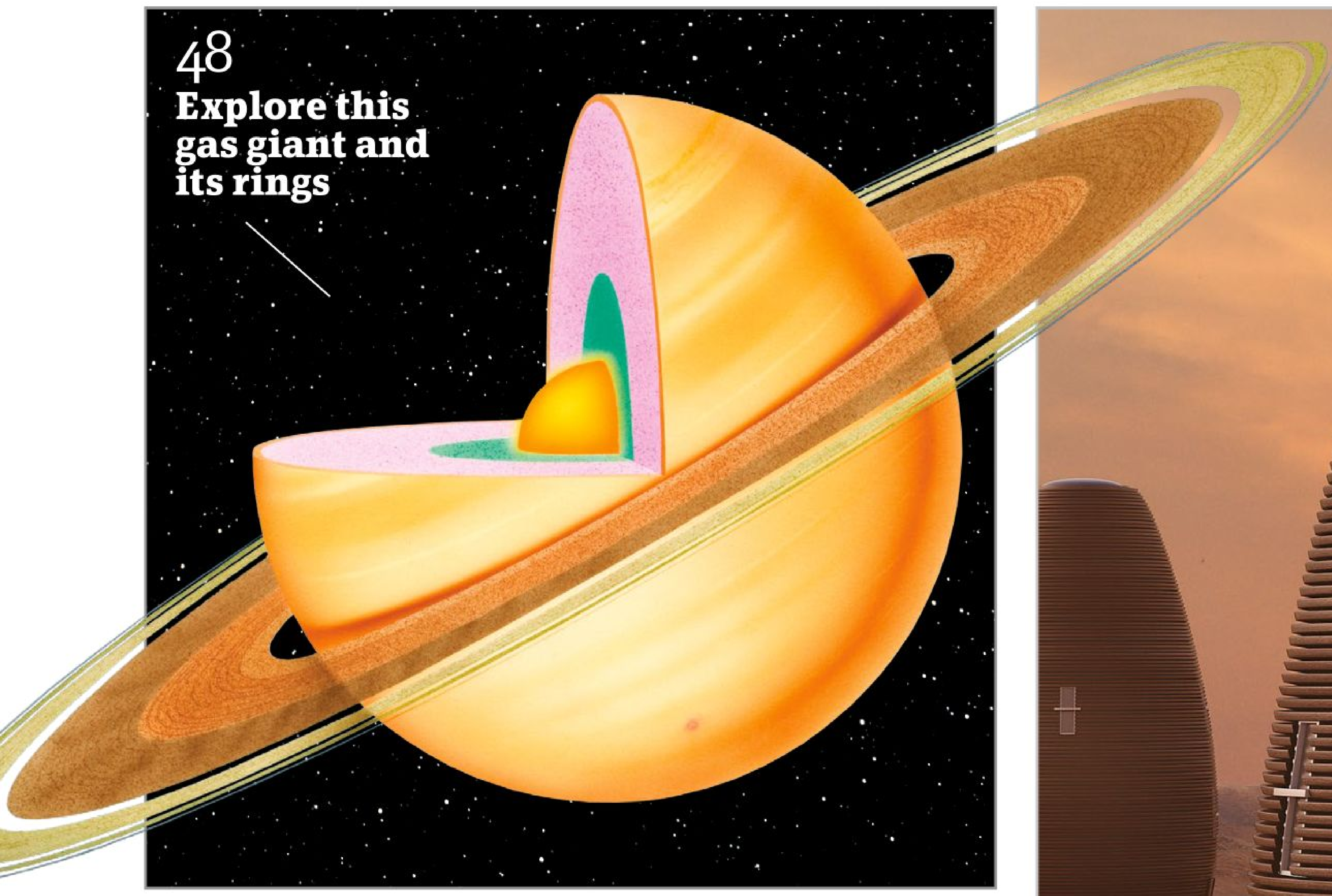


40
Discover the structure of Earth's parent star

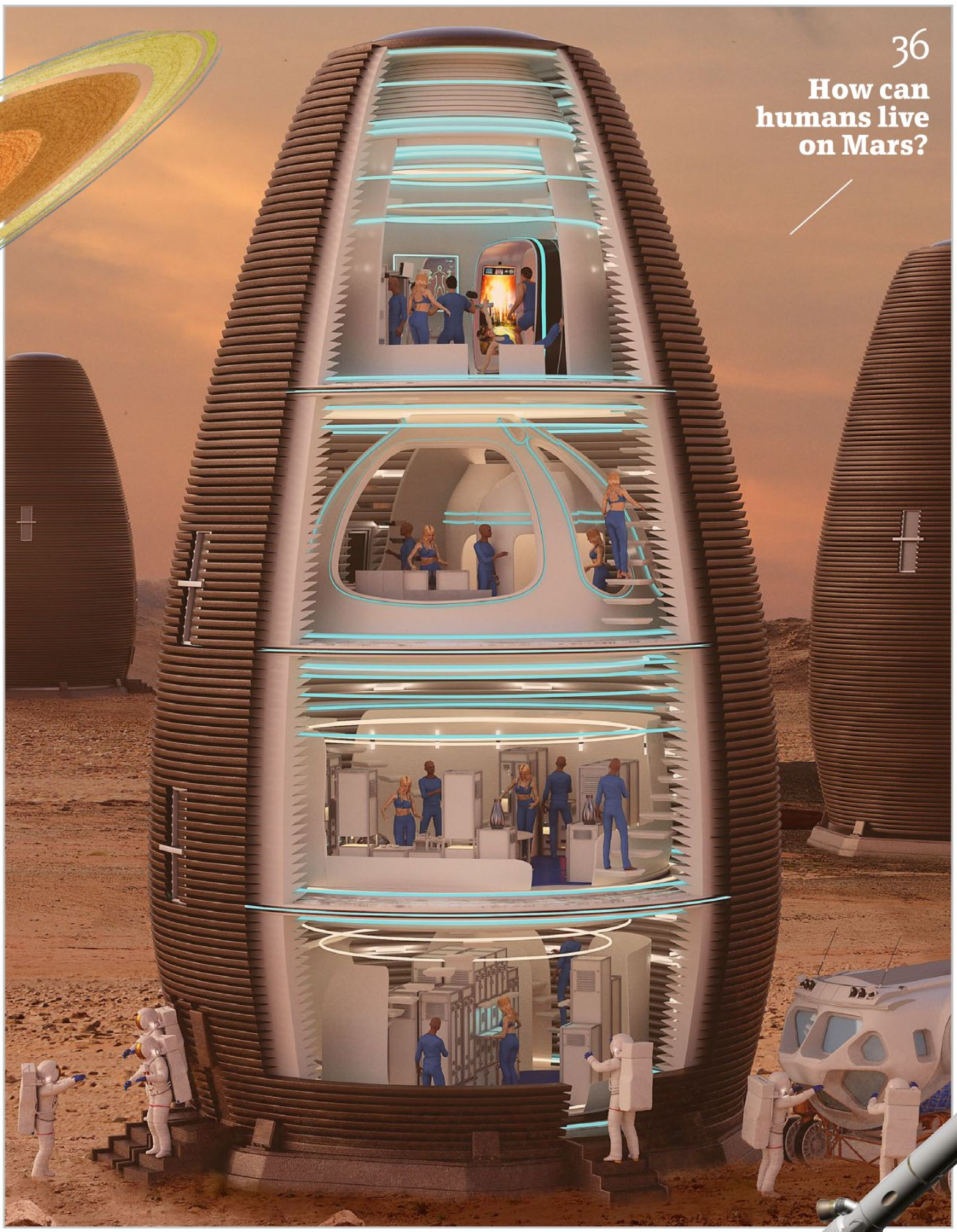
36 **Human habitats on Mars**
40 **Inside the Sun**
42 **The Shuttle orbiter**
44 **Testing the limits of spacecraft**
46 **The Orion spacecraft**
48 **Saturn**
50 **Neutron stars**
52 **Anatomy of the Apollo-Saturn V Moon rocket**



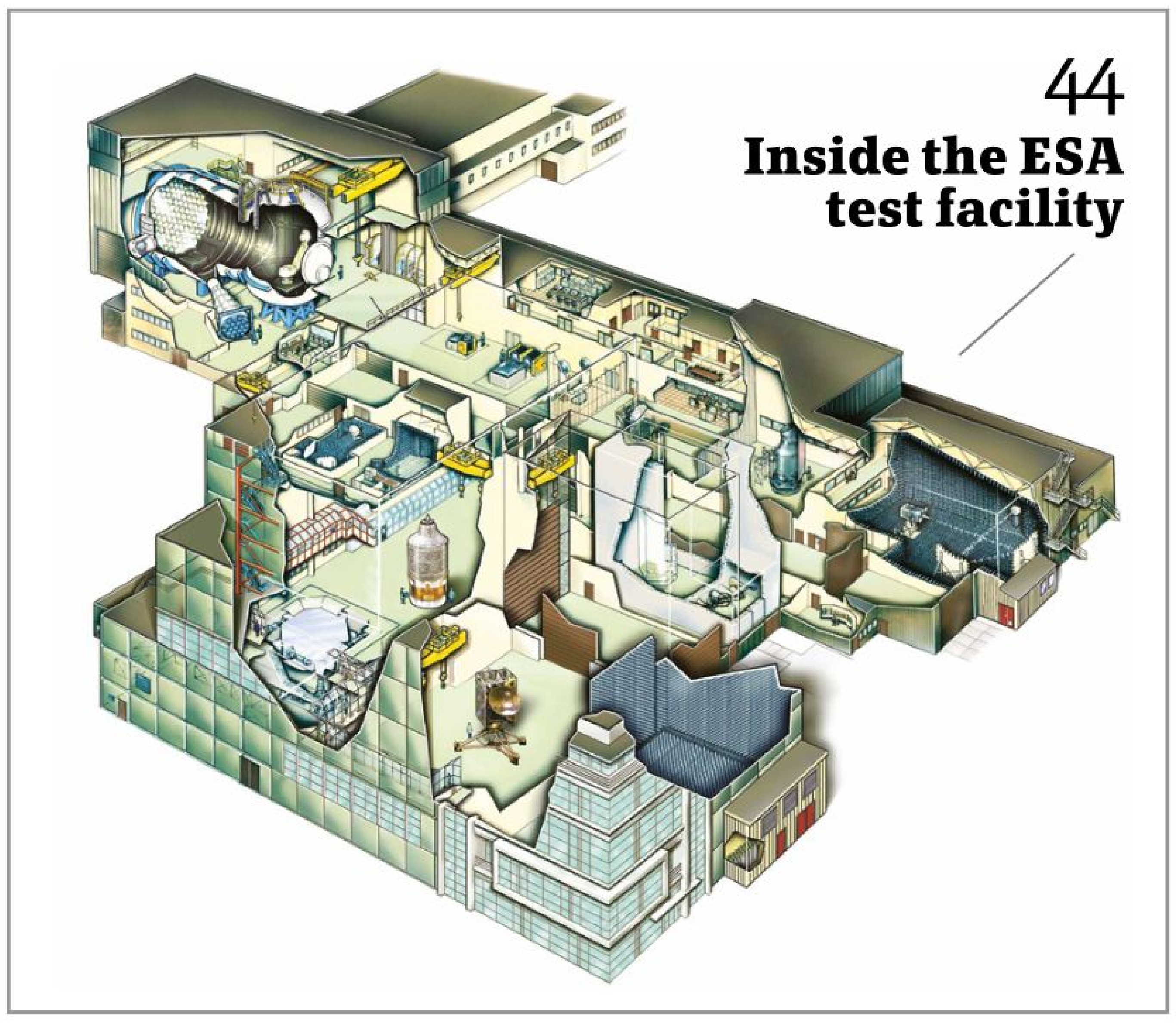
52
The essential anatomy of the Saturn V rocket



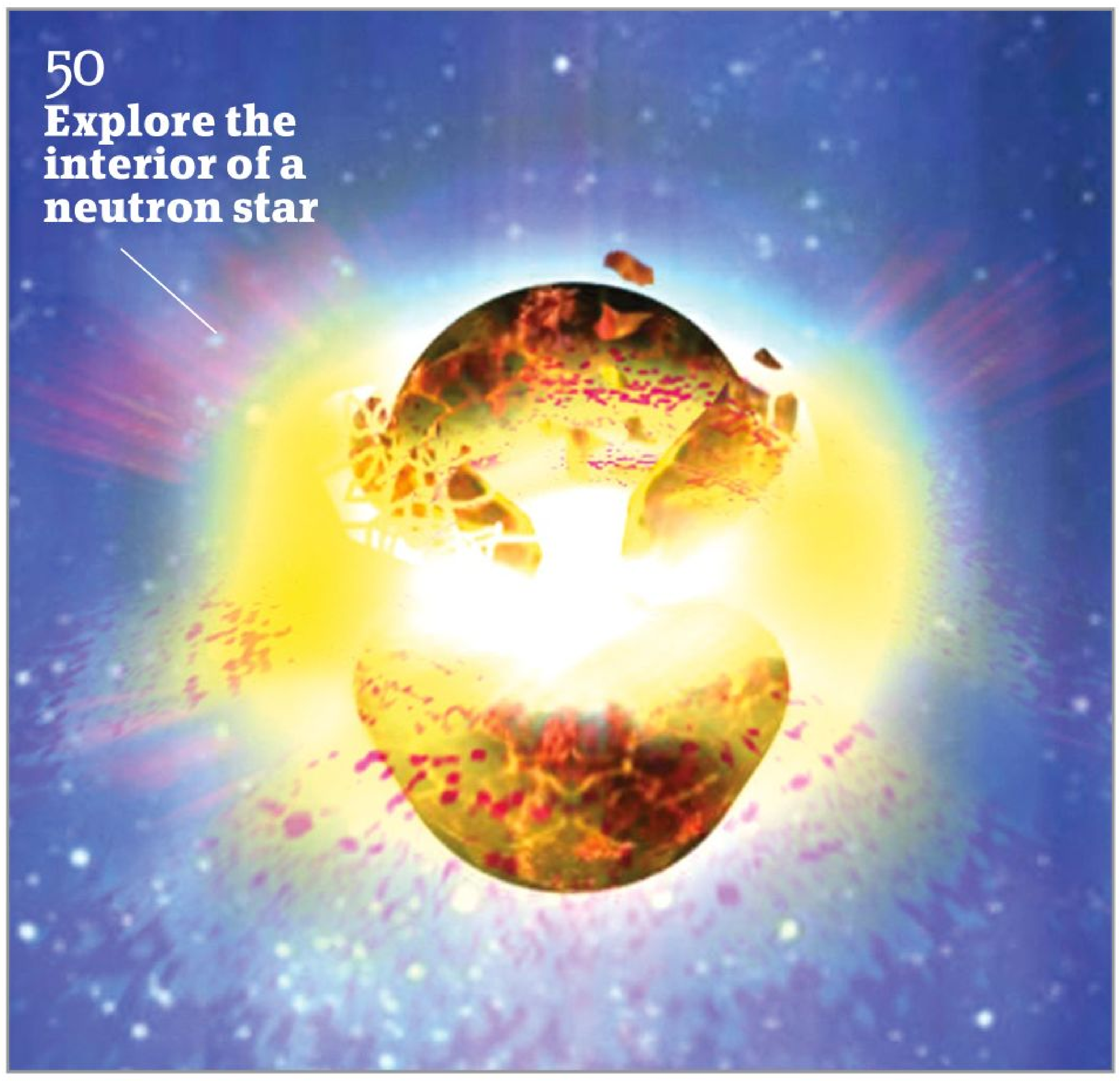
48
Explore this gas giant and its rings



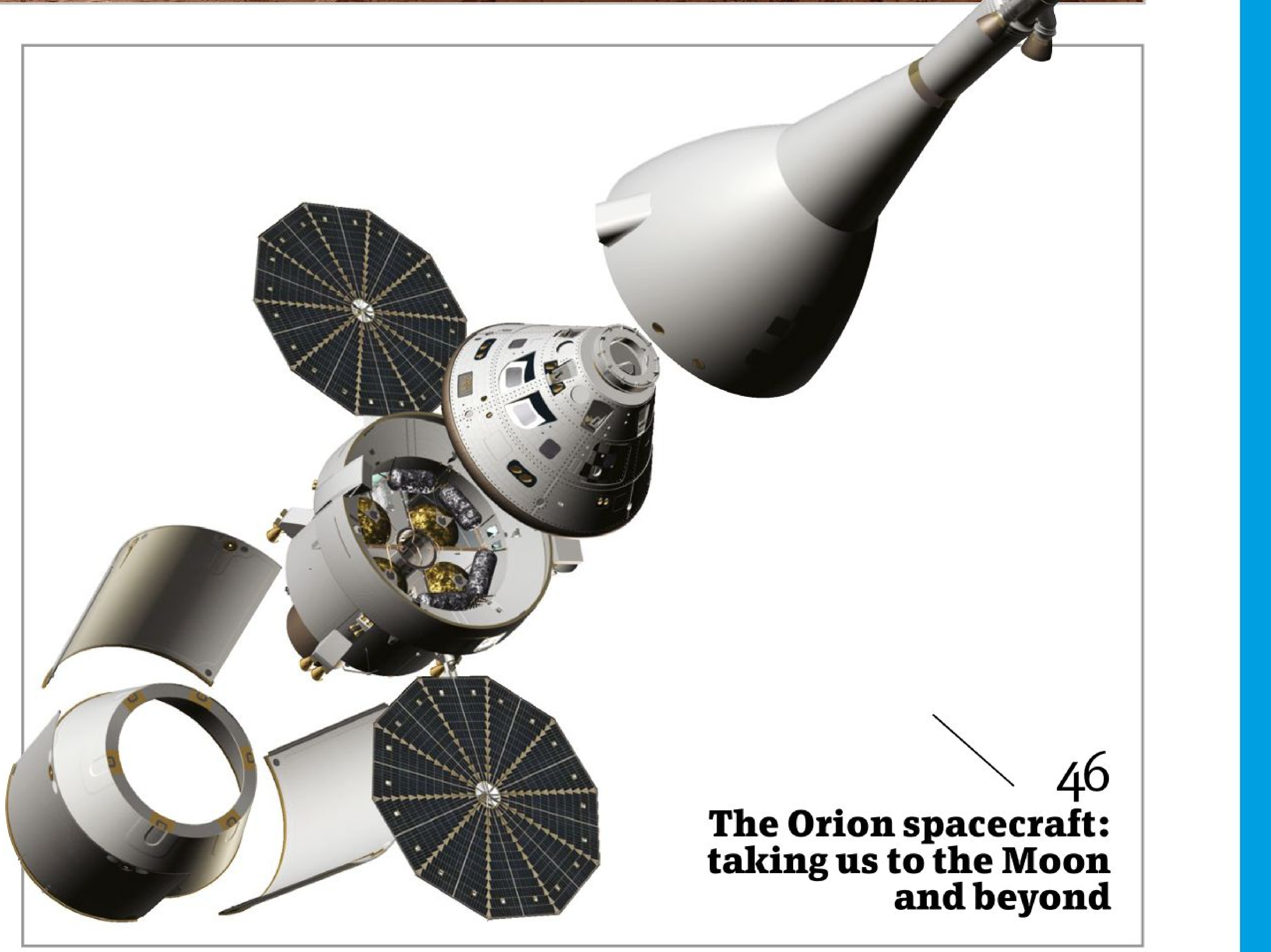
36
How can humans live on Mars?



44
Inside the ESA test facility



50
Explore the interior of a neutron star



46
The Orion spacecraft: taking us to the Moon and beyond

HUMAN HABITATS ON MARS

To survive on Mars, we'll need something to live in. Could these homes be the answer?

Words by **Jonathan O'Callaghan**

For decades, sending humans to Mars has been one of the main goals of our space exploration endeavours. Countries like the US and China, and companies such as SpaceX have all expressed a desire to colonise the Red Planet. But to do so, we will also need a way for humans to survive – and thrive – on the surface of this hostile world. And efforts have been long underway to do just that, by designing habitats that humans may live in.

Building a habitat on Mars poses particular challenges that are not faced anywhere on Earth. First there is the lack of pressure – about one per cent of Earth's at sea level – which means habitats must be pressurised. There are also vast temperature swings, from 20 degrees Celsius to as low as -153 degrees Celsius as day turns to night and the Sun's heat escapes through the thin atmosphere. A lack of obvious resources like building materials and water also poses a significant challenge, as does coping with less sunlight – about 44 per cent less than we experience here on Earth.

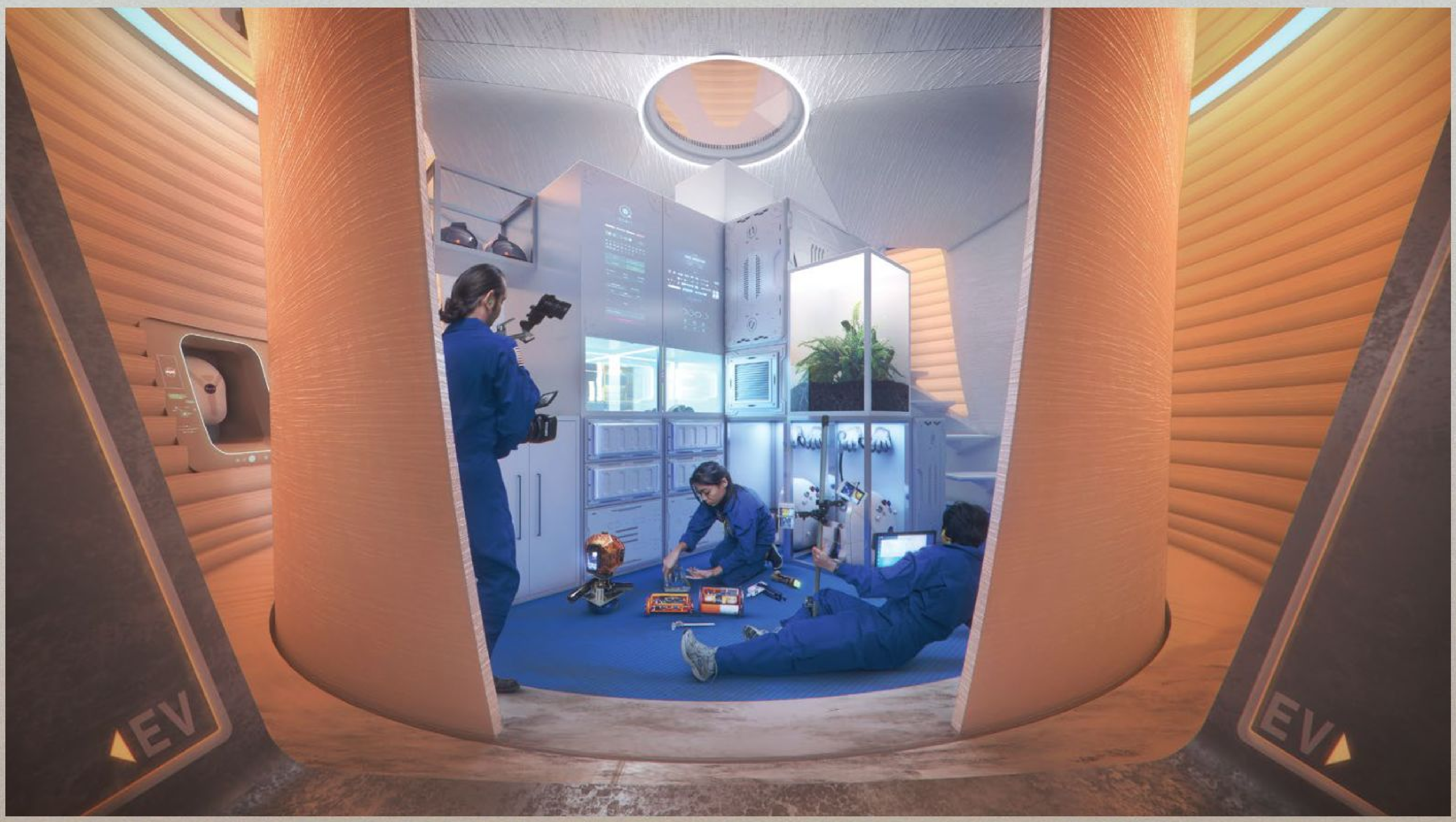
Entertainment will be important on Mars to stop the astronauts from getting bored

To overcome some of these challenges, NASA has been running the 3D-Printed Habitat Challenge since 2015, to see if anyone can come up with viable solutions to these problems. 3D-printing is deemed to be one of the best ways to build habitats on Mars, reducing the amount of mass that will need to be carried to the surface – especially if we can use Martian resources to print them.

In May 2019, two teams were awarded a combined $700,000 (around £580,000) to further develop the ideas they had suggested – one from New York-based AI SpaceFactory, called MARSHA, and another, Den@Mars, developed by Pennsylvania State University. Both make use of a curved structure in order to reduce the pressures on the habitat while on Mars. But while Den@Mars is a more traditional dome, MARSHA is a cylindrical shape – one of the factors that earned it the top prize from NASA of $500,000 (around £415,000), after successfully printing a one-third scale model of the design in 30 hours almost completely autonomously.

NASA hopes that these designs, or some variant of them, may form the basis of eventual Mars habitats when humans land there at some point in the 2030s or later. Many challenges remain, however, not least working out how to actually land the equipment on Mars that could print these structures, and ultimately sending humans there too. But if some of these challenges can be overcome in the near-term, it raises the prospect of eventual missions in the future.

The walls of the MARSHA habitat will be layered to block radiation and provide insulation



Mars materials

To build a habitat on Mars, MARSHA will use materials directly from the surface of Mars to reduce the amount of resources that need to be carried from Earth. The habitat will be built using basalt fibre extracted from the Martian rock, combined with a renewable bioplastic called polylactic acid (PLA) that can be processed from plants grown on Mars.

The resulting material has a similar strength to carbon fibre yet is much easier to make, while the plastic is a great shield against cosmic radiation. Using PLA also ensures the material is recyclable, and it will not expand and contract too much as temperatures on Mars change. The idea is that a machine on Mars, like a large crane, will be able to use this material to autonomously produce the habitats for astronauts to live inside, once the resources have been produced on the surface.

MARSHA habitats can be built on Mars to house many astronauts

"Building a habitat on Mars poses particular challenges"

The interior of the habitats will be fairly open and bright, promoting the astronauts' circadian rhythms

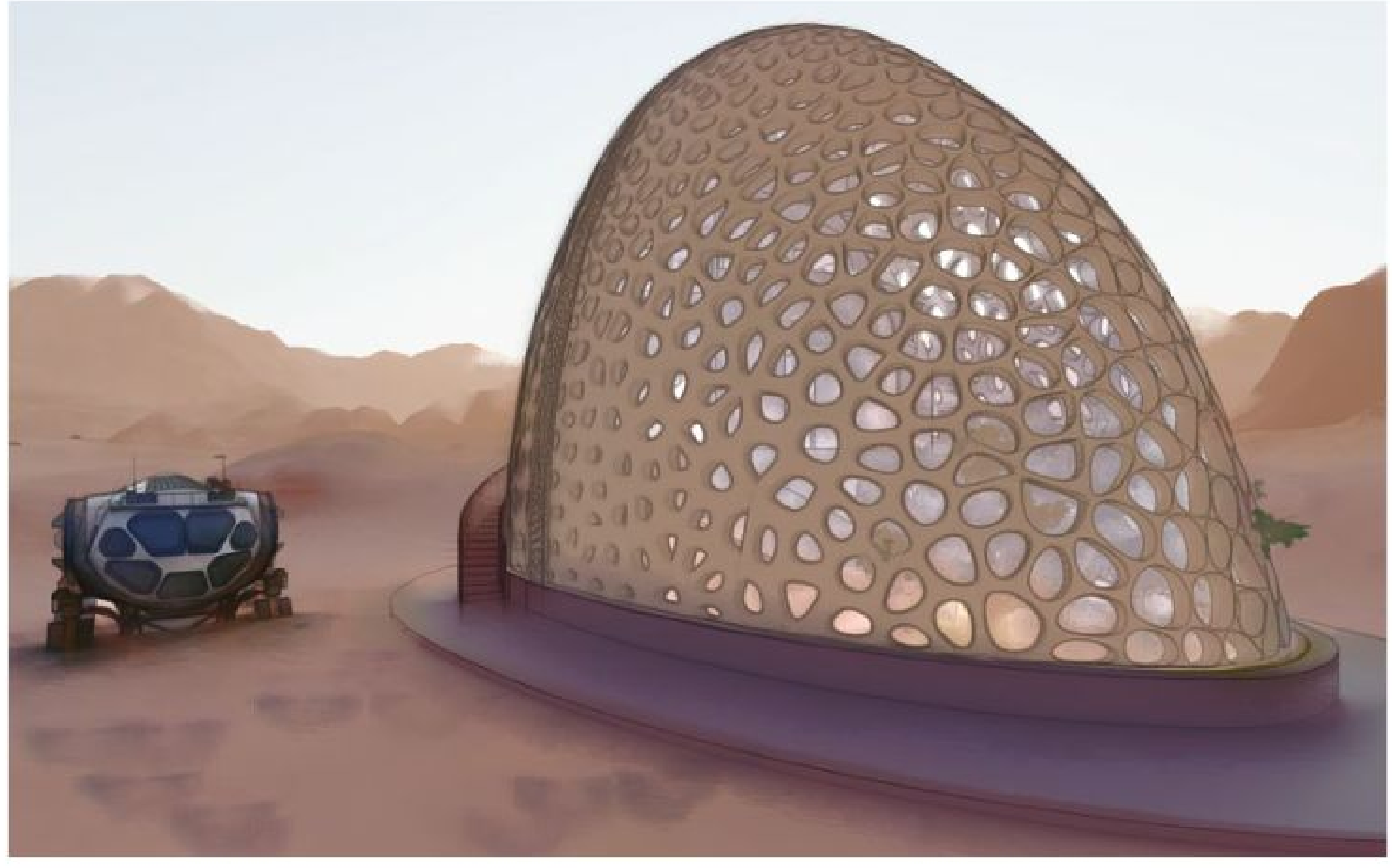
© AI SpaceFactory

Martian houses

Here are some of the other designs in NASA's Mars habitat competition that were considered

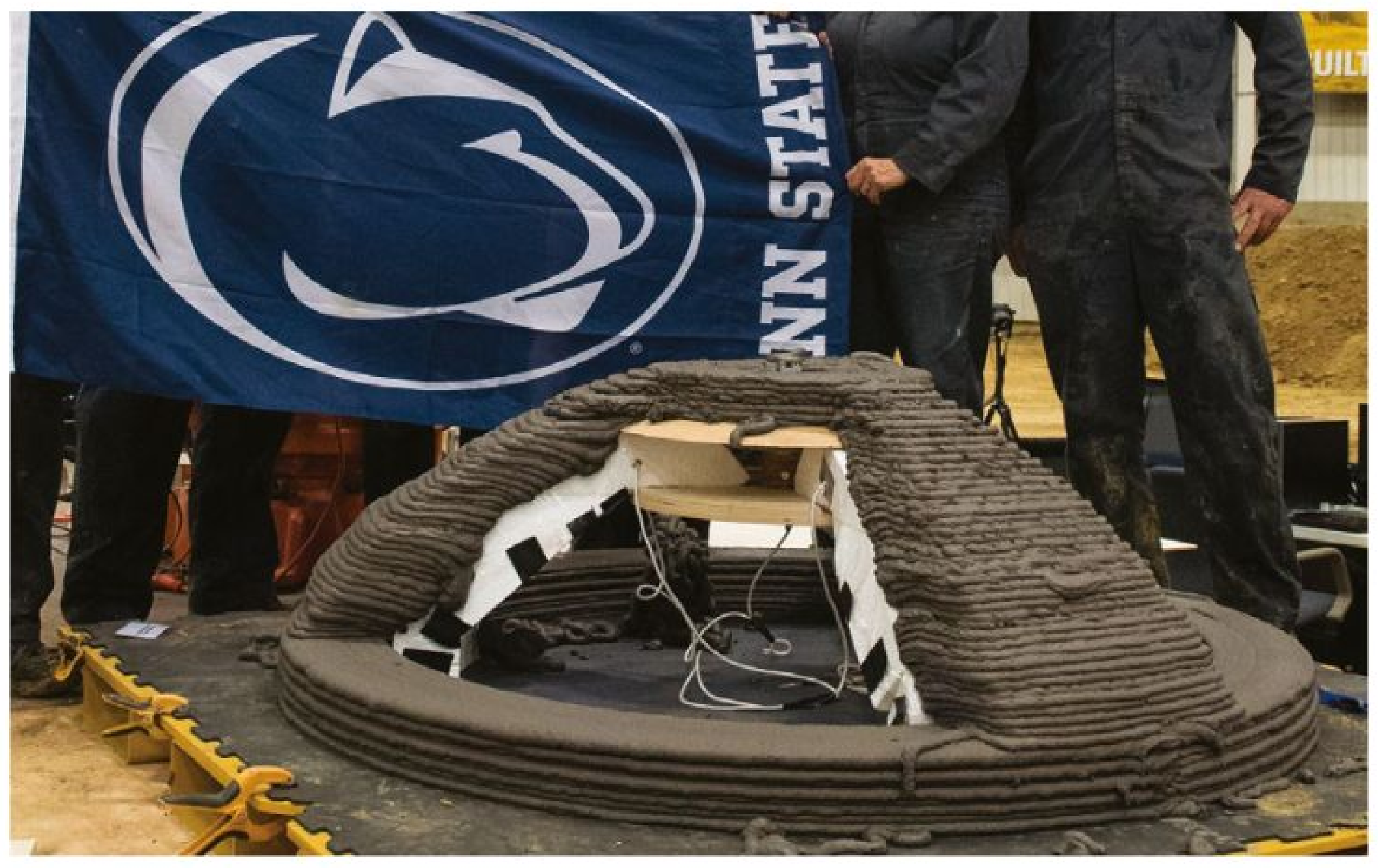
Team Kahn-Yates

This team from Jackson, Mississippi, designed a Martian habitat with a mottled design, that can cope with dust storms and the harsh climate on Mars.


© Team Kahn-Yates

Den@Mars

This idea from Pennsylvania State University planned to use digital scanning and a nozzle to squirt out a paste-like substance to produce a dome-shaped structure.



© Den@Mars

5 FACTS ABOUT

LIVING ON THE RED PLANET

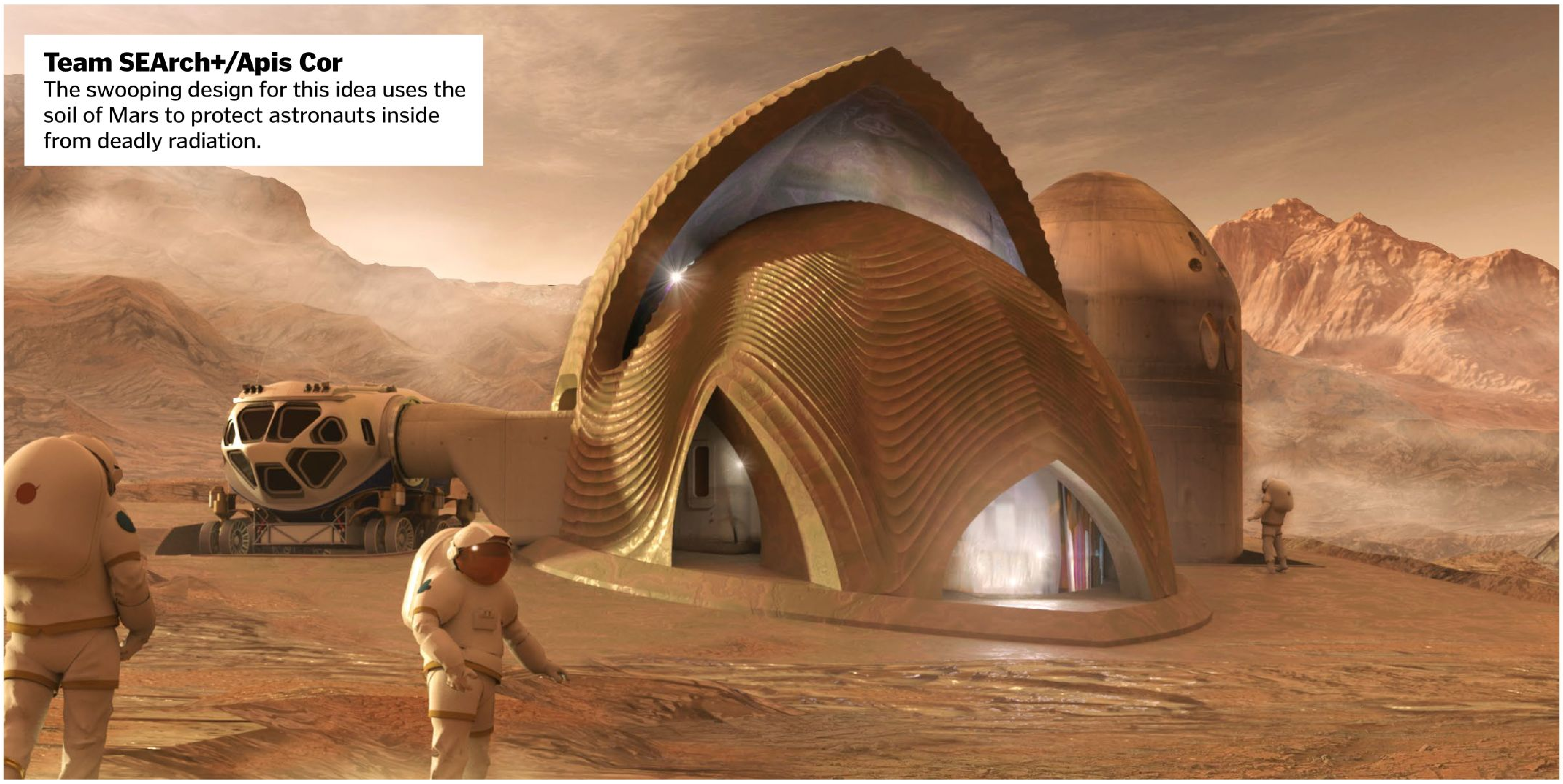
1 Lower gravity
Mars has just 38 per cent of Earth's gravity, so astronauts on Mars will need to exercise regularly to overcome any loss in bone density and muscle mass.

2 Space radiation
The thinner atmosphere of Mars means that astronauts will be exposed to much more solar and cosmic radiation, and must remain protected on the surface.

3 Launch windows
Owing to the orbits of Earth and Mars, missions between the two can only be launched every 26 months, and it will take about eight months to make the journey.

4 Martian water
Water cannot exist as a liquid on Mars because of the low pressure. But it's thought to be frozen under the surface as ice, which could be used by astronauts.

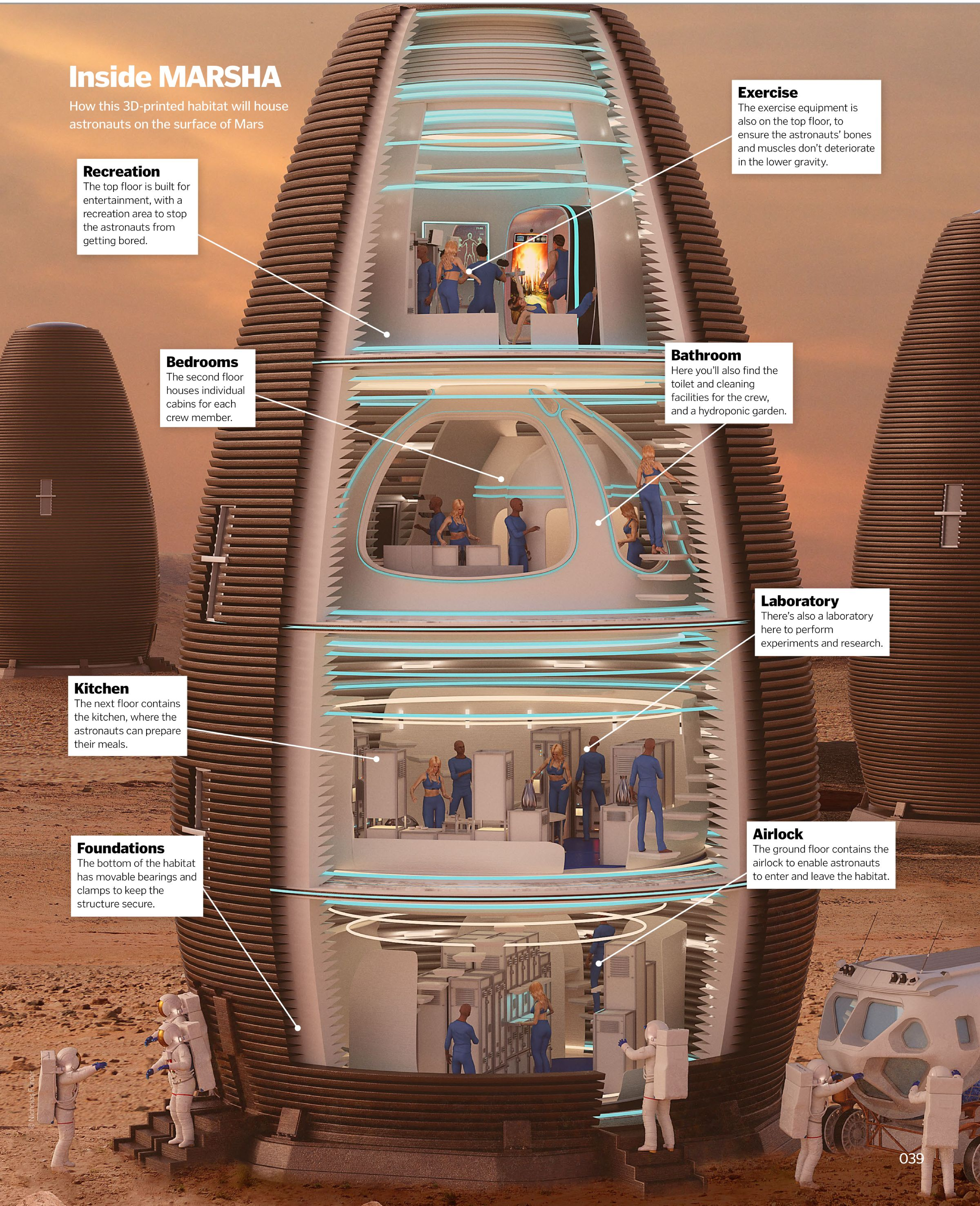
5 Life on Mars?
It's possible that Mars could play host to some form of microbial life. And perhaps it will take astronauts going there for us to find out for sure.


Team SEArch+/Apis Cor
The swooping design for this idea uses the soil of Mars to protect astronauts inside from deadly radiation.

© SpaceX

Inside MARSHA

How this 3D-printed habitat will house astronauts on the surface of Mars



Recreation
The top floor is built for entertainment, with a recreation area to stop the astronauts from getting bored.

Exercise
The exercise equipment is also on the top floor, to ensure the astronauts' bones and muscles don't deteriorate in the lower gravity.

Bedrooms
The second floor houses individual cabins for each crew member.

Bathroom
Here you'll also find the toilet and cleaning facilities for the crew, and a hydroponic garden.

Laboratory
There's also a laboratory here to perform experiments and research.

Kitchen
The next floor contains the kitchen, where the astronauts can prepare their meals.

Foundations
The bottom of the habitat has movable bearings and clamps to keep the structure secure.

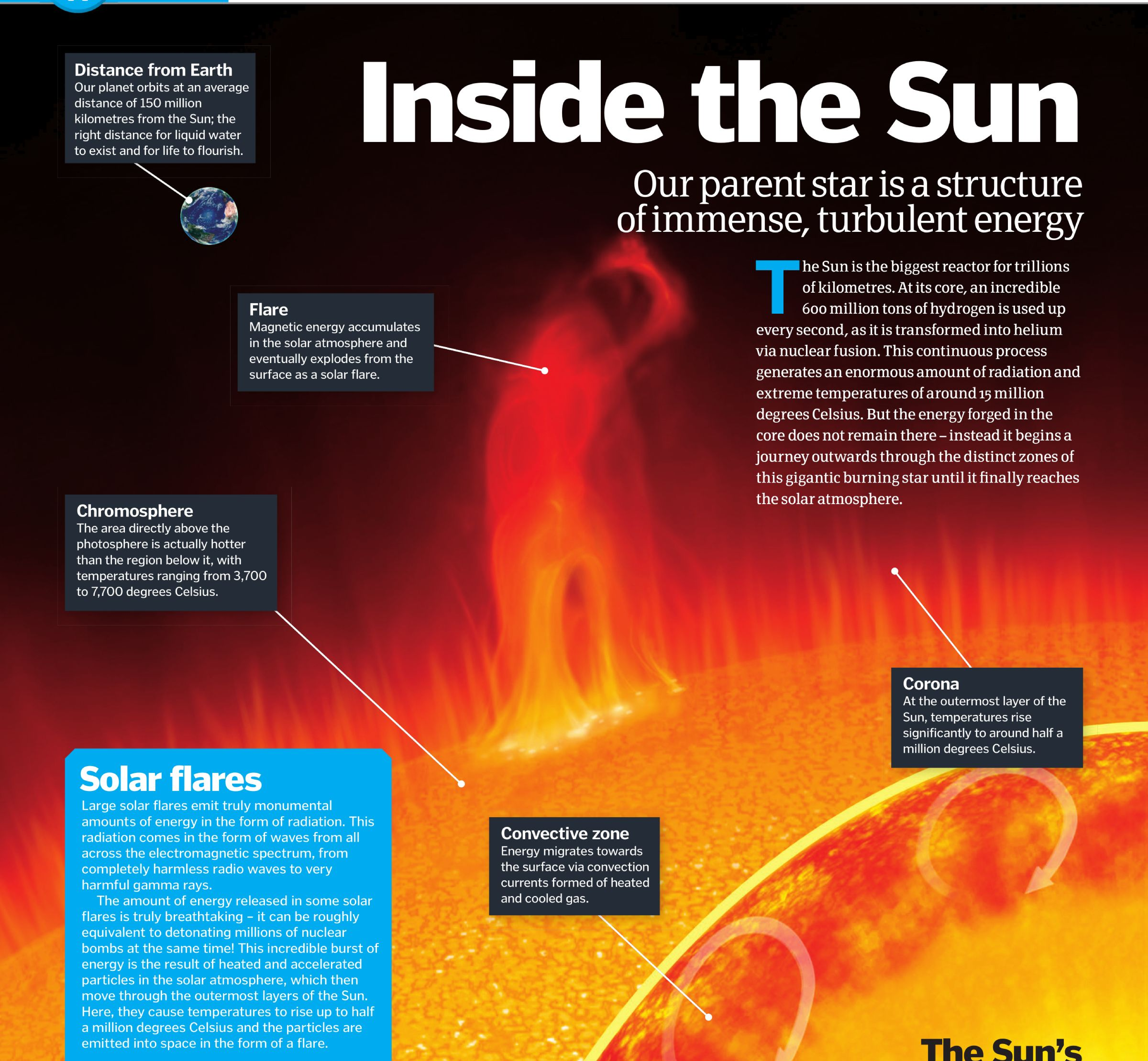
Airlock
The ground floor contains the airlock to enable astronauts to enter and leave the habitat.

© Nicholas Forder

Inside the Sun

Our parent star is a structure of immense, turbulent energy

The Sun is the biggest reactor for trillions of kilometres. At its core, an incredible 600 million tons of hydrogen is used up every second, as it is transformed into helium via nuclear fusion. This continuous process generates an enormous amount of radiation and extreme temperatures of around 15 million degrees Celsius. But the energy forged in the core does not remain there – instead it begins a journey outwards through the distinct zones of this gigantic burning star until it finally reaches the solar atmosphere.



The Sun's anatomy

Discover the structure of our local star

Distance from Earth
Our planet orbits at an average distance of 150 million kilometres from the Sun; the right distance for liquid water to exist and for life to flourish.

Flare
Magnetic energy accumulates in the solar atmosphere and eventually explodes from the surface as a solar flare.

Chromosphere
The area directly above the photosphere is actually hotter than the region below it, with temperatures ranging from 3,700 to 7,700 degrees Celsius.

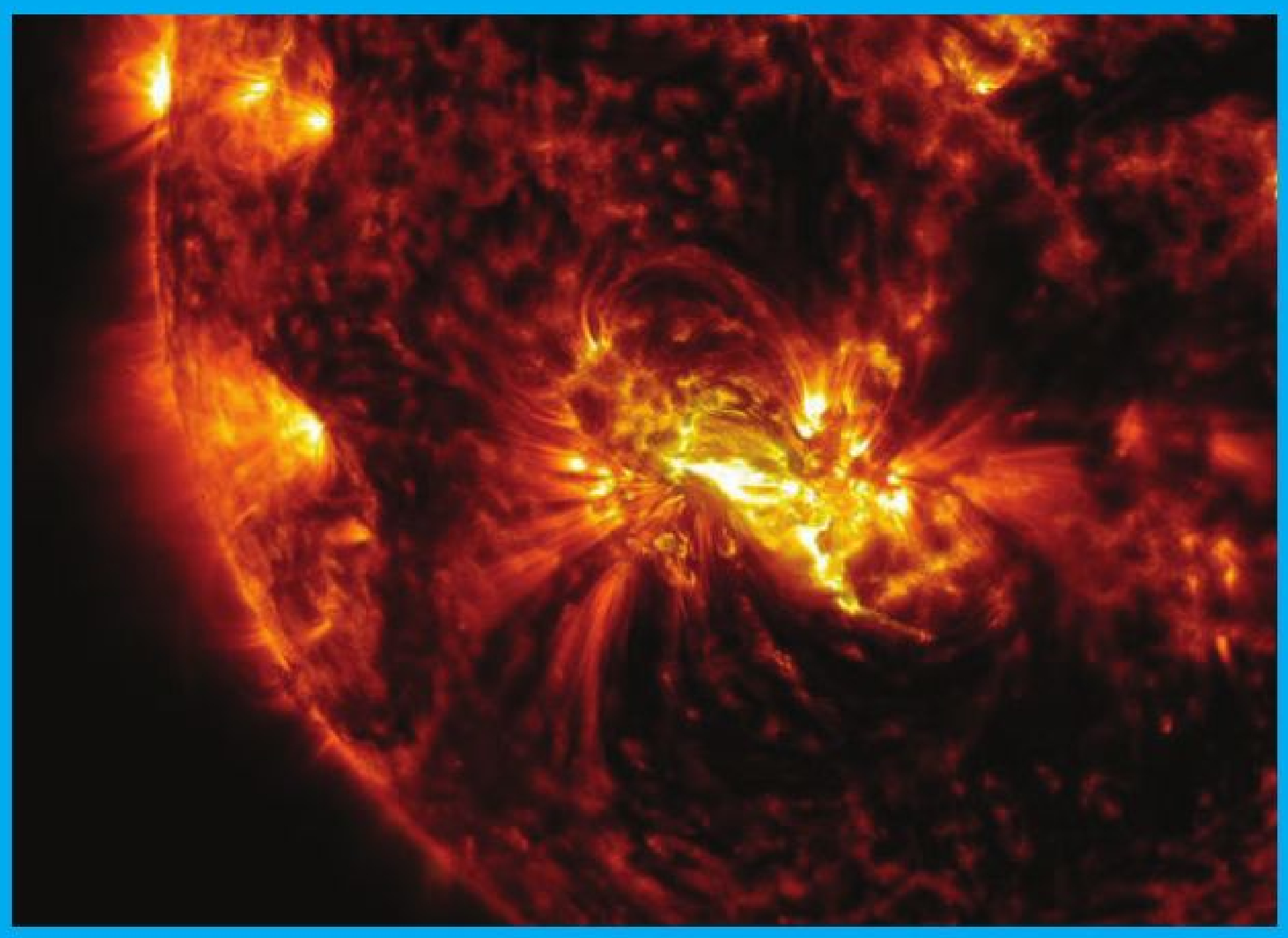
Corona
At the outermost layer of the Sun, temperatures rise significantly to around half a million degrees Celsius.

Convective zone
Energy migrates towards the surface via convection currents formed of heated and cooled gas.

Solar flares

Large solar flares emit truly monumental amounts of energy in the form of radiation. This radiation comes in the form of waves from all across the electromagnetic spectrum, from completely harmless radio waves to very harmful gamma rays.

The amount of energy released in some solar flares is truly breathtaking – it can be roughly equivalent to detonating millions of nuclear bombs at the same time! This incredible burst of energy is the result of heated and accelerated particles in the solar atmosphere, which then move through the outermost layers of the Sun. Here, they cause temperatures to rise up to half a million degrees Celsius and the particles are emitted into space in the form of a flare.



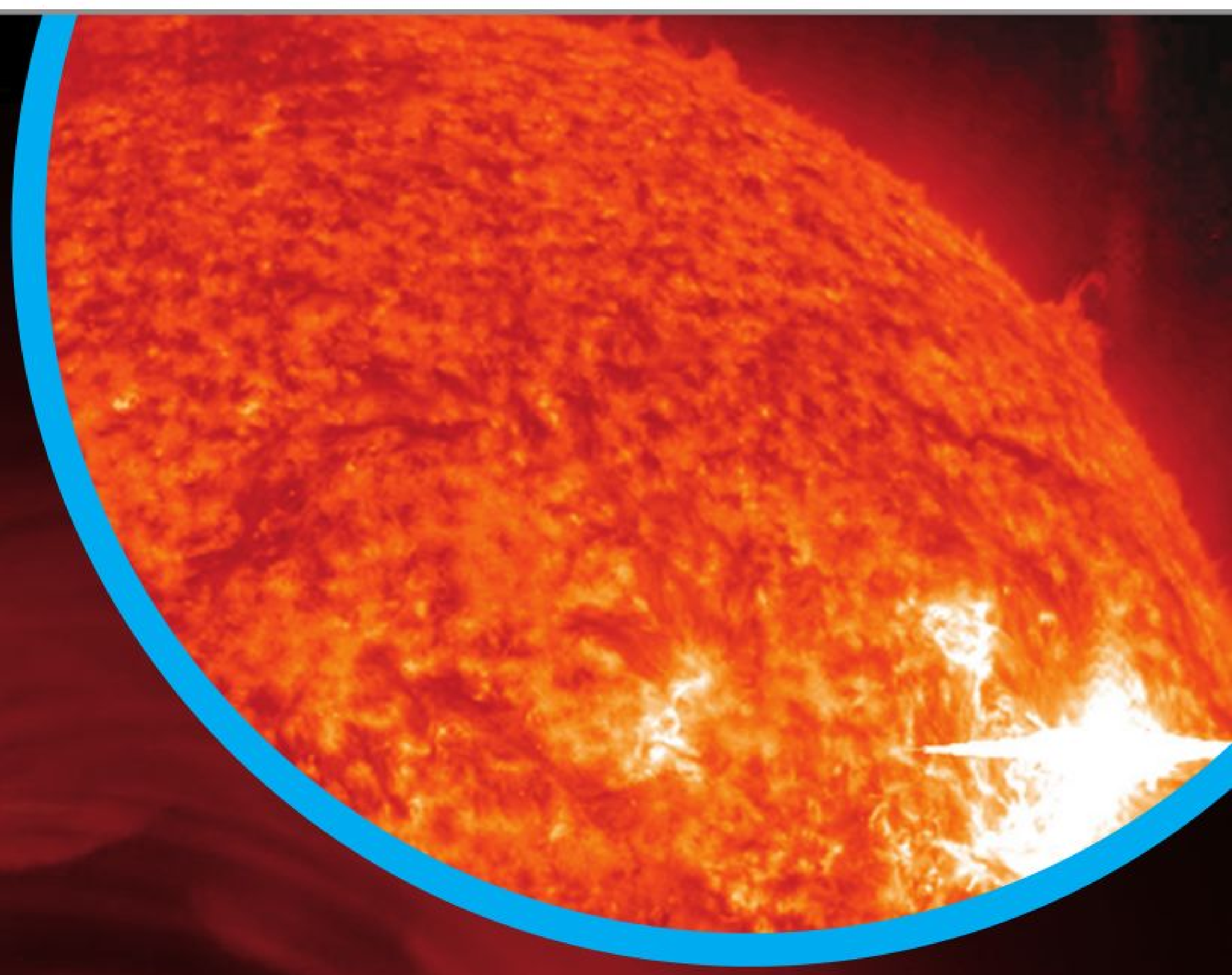
Solar flares release incredible amounts of energy in the form of radiation into the cosmos

DID YOU KNOW? *The Sun is about halfway through its predicted lifespan, and will run out of hydrogen fuel in about 5 billion years*

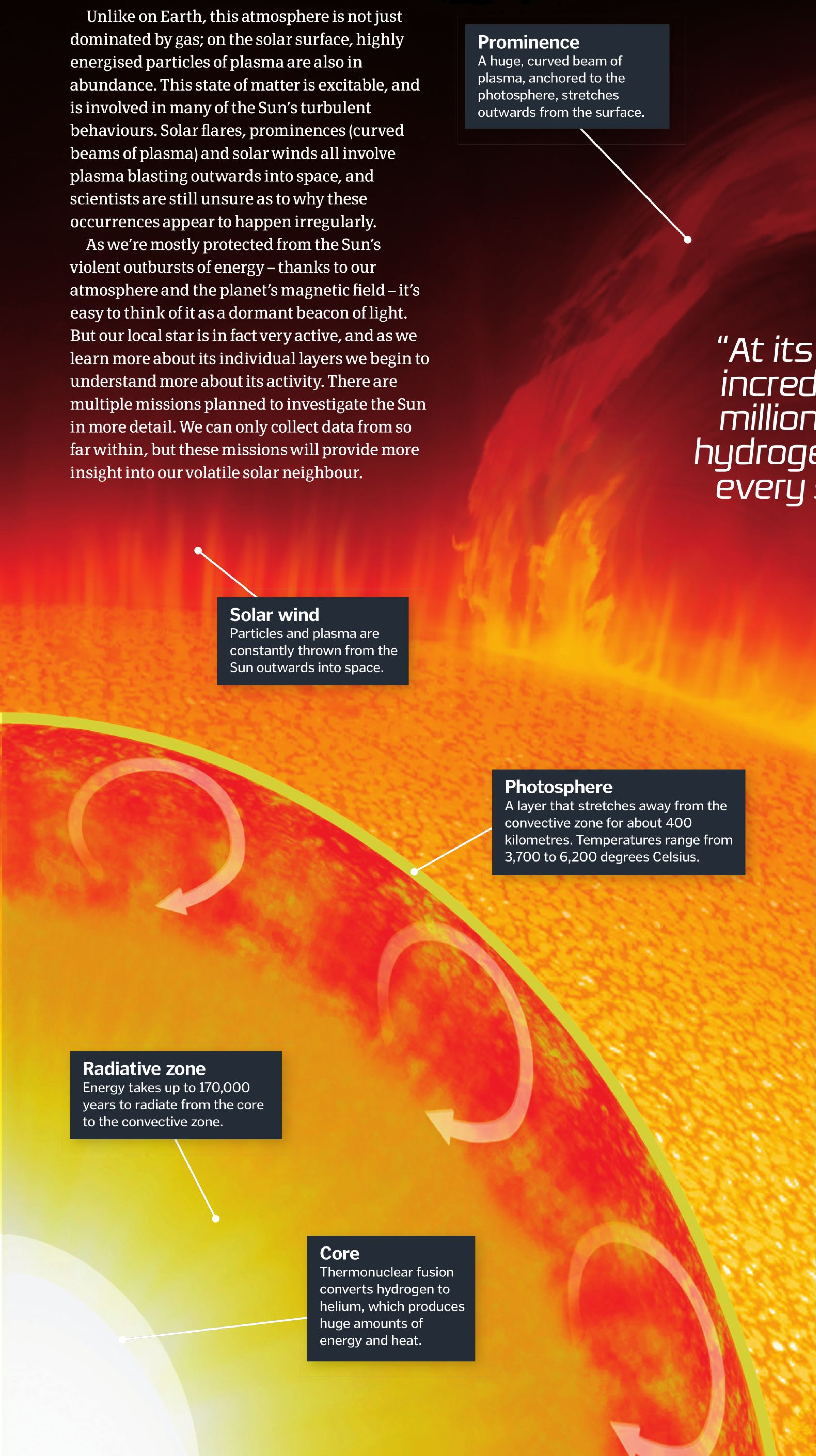
Unlike on Earth, this atmosphere is not just dominated by gas; on the solar surface, highly energised particles of plasma are also in abundance. This state of matter is excitable, and is involved in many of the Sun's turbulent behaviours. Solar flares, prominences (curved beams of plasma) and solar winds all involve plasma blasting outwards into space, and scientists are still unsure as to why these occurrences appear to happen irregularly.

As we're mostly protected from the Sun's violent outbursts of energy – thanks to our atmosphere and the planet's magnetic field – it's easy to think of it as a dormant beacon of light. But our local star is in fact very active, and as we learn more about its individual layers we begin to understand more about its activity. There are multiple missions planned to investigate the Sun in more detail. We can only collect data from so far within, but these missions will provide more insight into our volatile solar neighbour.

> *"At its core, an incredible 600 million tons of hydrogen is used every second"*



The Sun is a much more turbulent entity than most people realise



Prominence
A huge, curved beam of plasma, anchored to the photosphere, stretches outwards from the surface.

Solar wind
Particles and plasma are constantly thrown from the Sun outwards into space.

Photosphere
A layer that stretches away from the convective zone for about 400 kilometres. Temperatures range from 3,700 to 6,200 degrees Celsius.

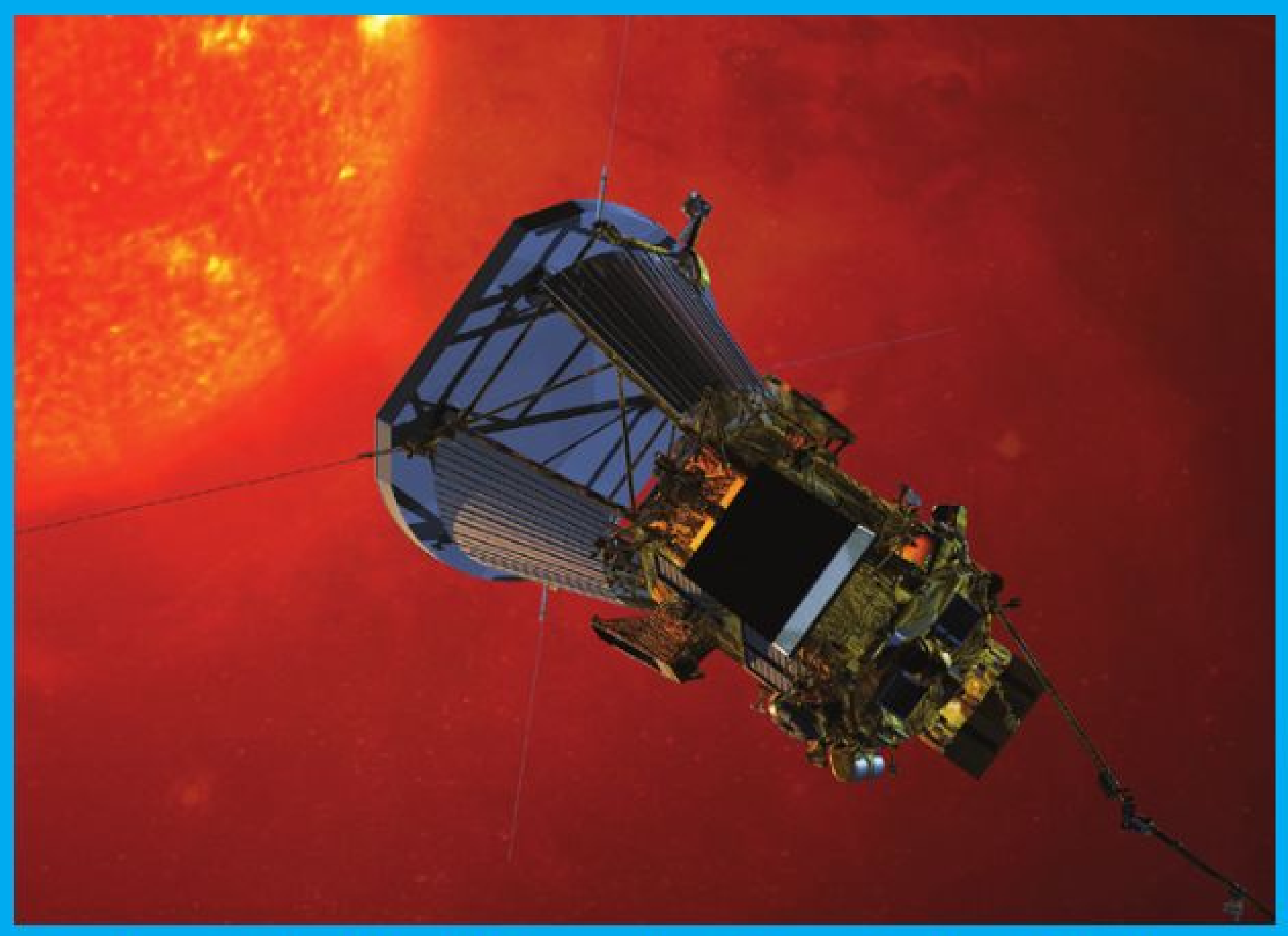
Radiative zone
Energy takes up to 170,000 years to radiate from the core to the convective zone.

Core
Thermonuclear fusion converts hydrogen to helium, which produces huge amounts of energy and heat.

Studying the Sun

Although researchers now know more about the Sun than ever before, it still holds many mysteries. NASA's Solar Probe Plus, currently scheduled for launch in 2018, aims to fly seven-times closer to the Sun's surface than any previous mission in order to collect new data on solar activity.

The probe will have to withstand extreme heat and radiation as it travels within Mercury's orbit, swooping within 6.2 million kilometres of the Sun's surface. To cope with such conditions, the probe will be fitted with an 11.4-centimetre-thick heat shield, enabling it to operate when external temperatures are over 1,300 degrees Celsius. But at least power won't be a concern; at such close proximity, the craft's solar arrays will receive more than enough energy.

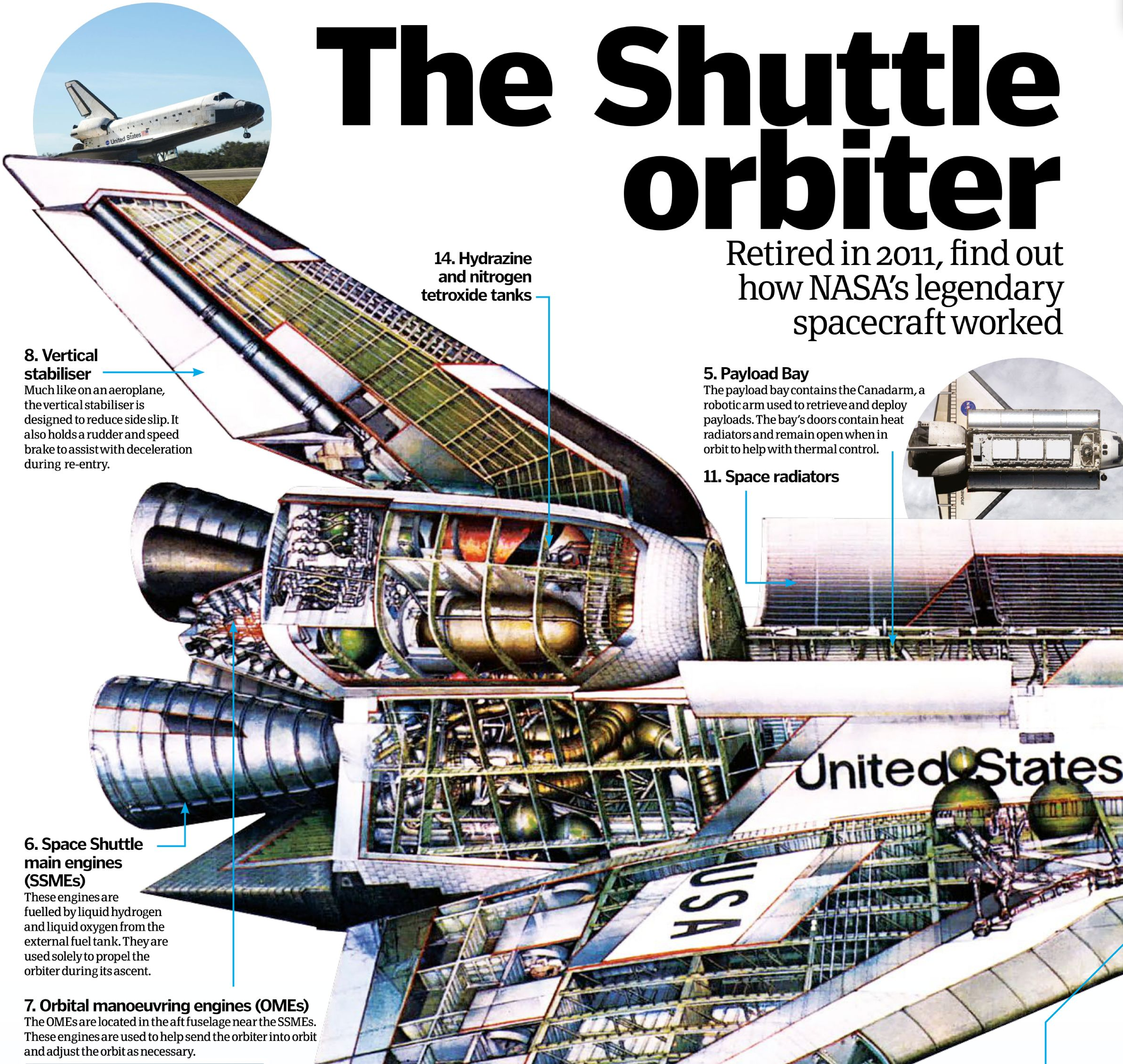


The heat shield will keep the Solar Probe Plus' instruments cool enough to function

© NASA; SPL

The Shuttle orbiter

Retired in 2011, find out how NASA's legendary spacecraft worked



14. Hydrazine and nitrogen tetroxide tanks

8. Vertical stabiliser
Much like on an aeroplane, the vertical stabiliser is designed to reduce side slip. It also holds a rudder and speed brake to assist with deceleration during re-entry.

5. Payload Bay
The payload bay contains the Canadarm, a robotic arm used to retrieve and deploy payloads. The bay's doors contain heat radiators and remain open when in orbit to help with thermal control.

11. Space radiators

6. Space Shuttle main engines (SSMEs)
These engines are fuelled by liquid hydrogen and liquid oxygen from the external fuel tank. They are used solely to propel the orbiter during its ascent.

7. Orbital manoeuvring engines (OMEs)
The OMEs are located in the aft fuselage near the SSMEs. These engines are used to help send the orbiter into orbit and adjust the orbit as necessary.

10. Main gear
Upon re-entry, the crew manually deploys the orbiter's landing gear in the form of three sets of wheels through the heat shield.

Endeavour after launch for mission STS-118

9. Elevons
The elevons are located on the edges of the wings. They are used for both roll control and pitch control during landing.

Inside the Shuttle

Under the skin of the Shuttle's surface

5 TOP FACTS
SPACE SHUTTLE MISSIONS

STS-7: Space Shuttle Challenger
1 Launched on 18 June 1983, this marked the first time that an American female astronaut entered space with the inclusion of Sally K. Ride.

STS-31: Space Shuttle Discovery
2 Launching on 24 April 1990, the crew of the Space Shuttle Discovery deployed the Hubble Space Telescope during STS-31.

STS-71: Space Shuttle Atlantis
3 On 27 June 1995, the Atlantis launched STS-71. This mission marked the first time that the Space Shuttle docked with the Russian space station Mir.

STS-88: Space Shuttle Endeavour
4 Launched on 4 December 1998, STS-88 was the first mission to the ISS. As its payload, it carried the first US node for the ISS, Unity.

STS-95: Space Shuttle Discovery
5 Discovery's 25th flight launched on 29 October 1998. It is also well-known as John Glenn's return to space at the age of 77.

DID YOU KNOW? *Upon re-entry, the external Shuttle skin withstands temperatures as high as 1,648° Celsius*

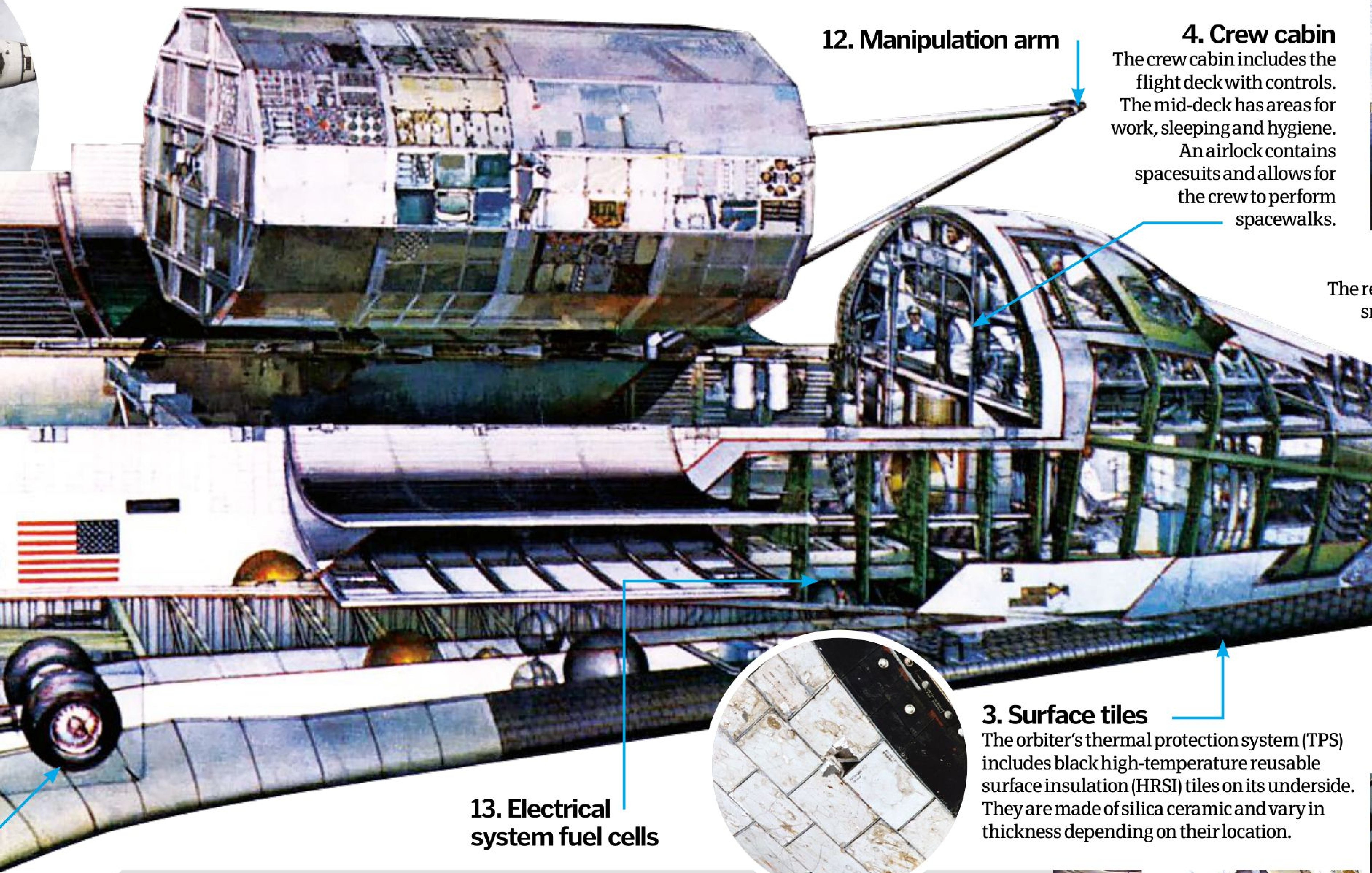
What we think of as the 'Space Shuttle', NASA called the Space Shuttle transport orbital vehicle or orbiter (STS-OV, or just OV). It was a reusable winged plane-like spacecraft. In addition to its engines and thrusters, it also had a three-level crew cabin and a payload bay.

The orbiter fleet had five different craft. The first was the Columbia, launched on 12 April 1981, followed by the Challenger, Discovery, Atlantis and Endeavour orbiters (the latter built to replace Challenger). Although all of the orbiters were similar, rotating maintenance meant that each was somewhat unique. The Endeavour was the last orbiter in the fleet, first launched on 7 May 1992. The Discovery, Atlantis and Endeavour were still in use until their retirement in 2011. On 28 January 1986, the Challenger was destroyed a little more than a minute into its tenth mission. A seal on one of the SRBs failed, which caused it to leak flames onto the external fuel tank. The orbiter veered and was torn apart by as much as 20 Gs of aerodynamic force, which resulted in the death of its seven-member crew.

On 1 February 2003, the Columbia was destroyed upon re-entry into the atmosphere, killing its seven crew members. This occurred when gases entered one of the orbiter's wings through a hole made by a piece of foam during launch and caused a structural failure.

Discovery approaches the ISS for docking

A simulation of handling large objects in space



12. Manipulation arm

4. Crew cabin
The crew cabin includes the flight deck with controls. The mid-deck has areas for work, sleeping and hygiene. An airlock contains spacesuits and allows for the crew to perform spacewalks.

2. RCS thrusters
The reaction control system (RCS) comprises 44 small thrusters located around the orbiter. They are used for close manoeuvring such as docking, orientation and altitude control.

1. Nose cap
The orbiter's nose is made of a carbon fibre and graphic composite known as reinforced carbon-carbon (RCC), which protects the orbiter from the 1,650° Celsius heat during re-entry.

3. Surface tiles
The orbiter's thermal protection system (TPS) includes black high-temperature reusable surface insulation (HRSI) tiles on its underside. They are made of silica ceramic and vary in thickness depending on their location.

13. Electrical system fuel cells

Where the action is

Crew on the flight deck performed duties ranging from piloting the Shuttle to satellite launches

The orbiter's flight deck was home to the mission's commander, pilot and two mission specialists. It looked much like the cockpit of an aeroplane, but with more controls – over 2,000 buttons, switches, dials and displays in total. In addition to forward controls in front of the commander and pilot, the flight deck also had displays and controls on its aft side. These were used to operate payloads.

The duties of the commander, pilot and specialists while on the flight deck depended on the details of the mission. In addition to firing the orbital manoeuvring engines (OMEs) to take the Shuttle in and out of orbit, the pilot also steered the Shuttle to rendezvous with the ISS or other crafts. Mission specialists conducted experiments or retrieved and released satellites from the payload bay.

All images © NASA

Testing the limits of spacecraft

Take a look inside the European Space Agency's high-tech testing facility

The European Space Agency (ESA) brings more than 20 countries together in pursuit of space travel, and its largest facility can be found at Noordwijk, on the west coast of the Netherlands. The European Space Research and Technology Centre (ESTEC) is the high-tech hub of the operation, responsible for making sure that all spacecraft and their payloads are fit to fly.

Travelling to space is a challenge. Spacecraft are exposed to extreme speeds, extreme temperatures, and extreme vibration. They will enter a vacuum, undergo weightlessness, and be pummelled with radiation, so before the spacecraft set off into these unforgiving conditions, the ESA team needs to make sure that they are ready.

More than 2,500 people work at ESTEC, designing the blueprints for new missions, developing new technology, and checking every spacecraft before launch. Each new item needs to be tested, and the facility is equipped to mimic the stresses of outer space as closely as possible.

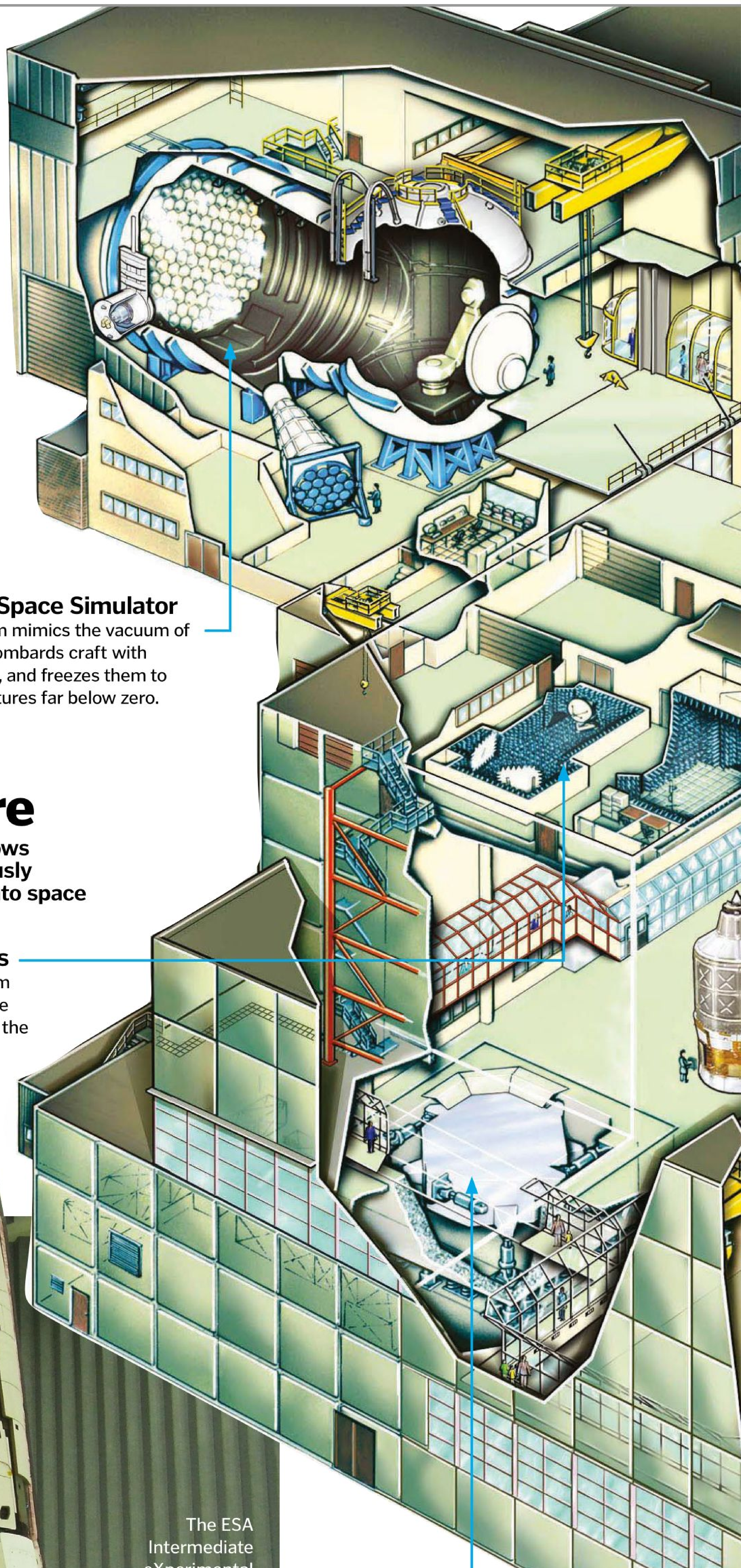
The self-contained facility was specially designed to allow spacecraft to move from one area to the next, undergoing a sequence of tests to ensure that they are ready to fly. All the rooms are kept behind airlocks, ensuring that the craft remain clean and protected throughout their stay.

Inside the centre's various rooms, the equipment is shaken, spun, blasted with sound, frozen, bombarded with radiation and exposed to a vacuum. Each room is specifically designed to test a different aspect of the launch and space-travel process. For instance, the Large European Acoustic Facility acts like a giant music speaker, blasting satellites with the kind of volumes they will need to endure at lift-off. Next, the craft may be exposed to the extreme temperatures of space for a period of several weeks.

While the spacecraft and components undergo rigorous tests, the Data Handling Systems collect and analyse information from hundreds of sensors. Once they have passed every challenge that the Test Centre throws at them, the spacecraft are ready to make the dangerous trip into space.

Inside the Test Centre

A network of rooms allows spacecraft to be rigorously tested before they go into space

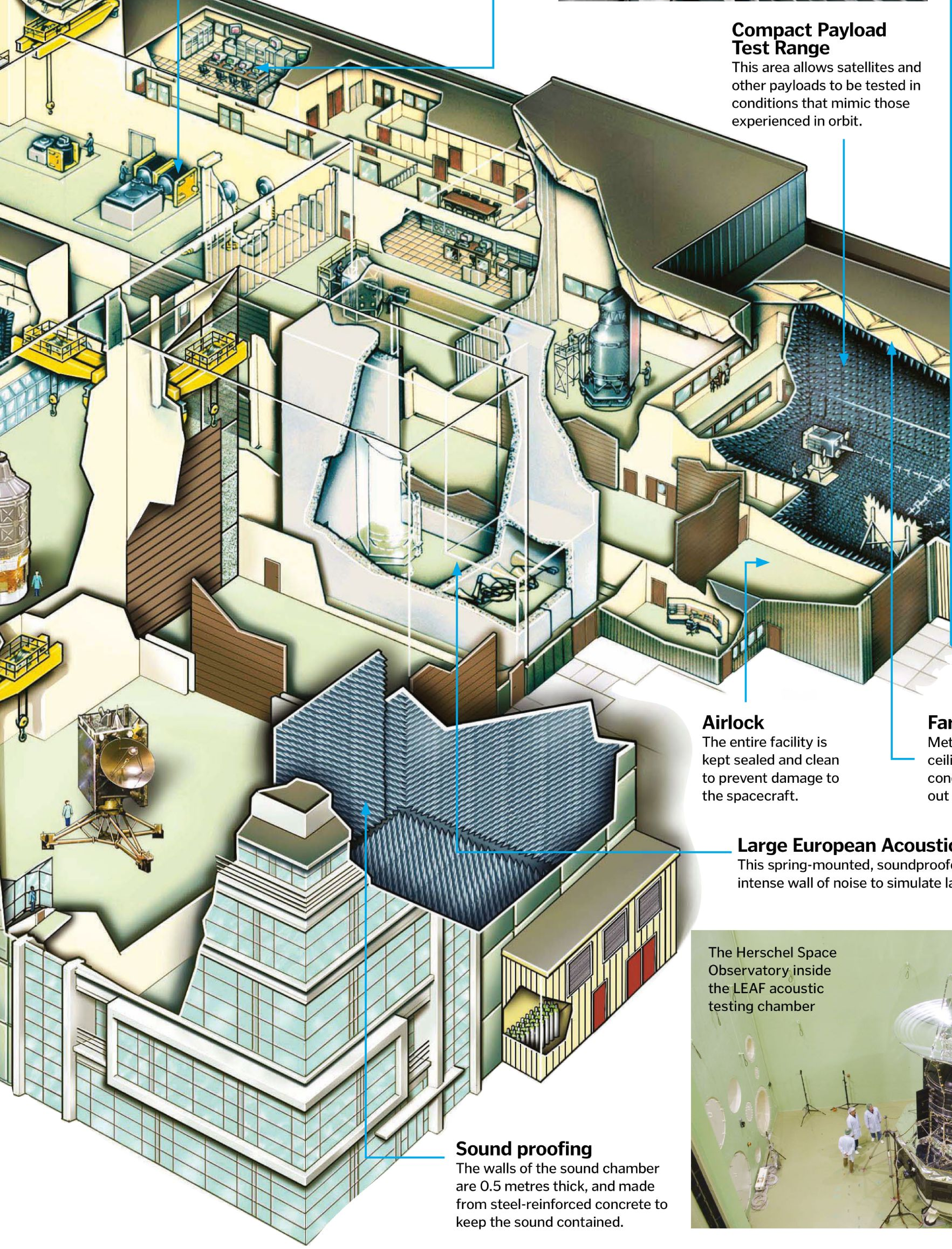


Large Space Simulator
This room mimics the vacuum of space, bombards craft with radiation, and freezes them to temperatures far below zero.

Electromagnetic compatibility facilities
These rooms are shielded from external radiation, allowing the electromagnetic emissions of the spacecraft itself to be tested.

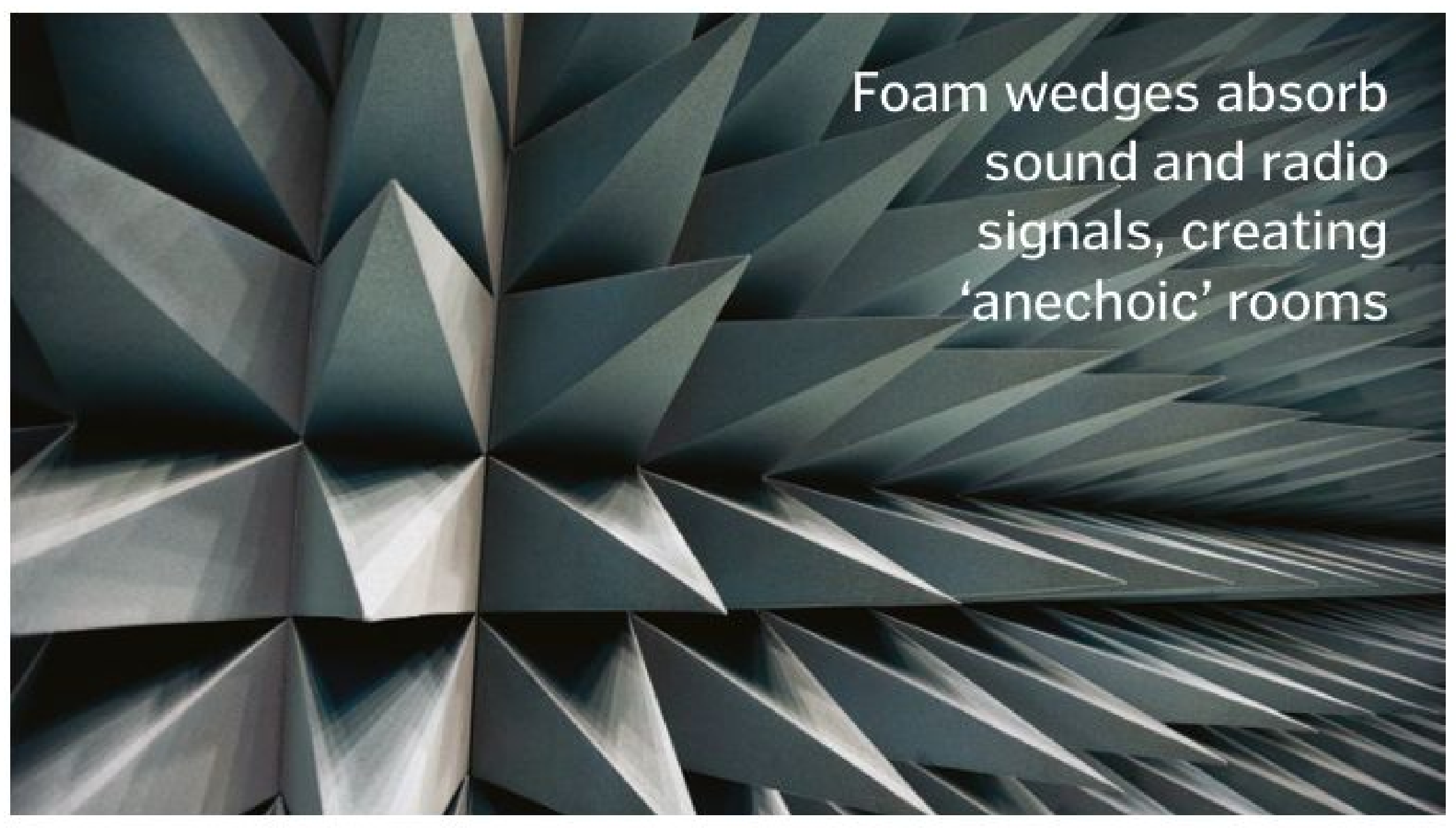
Hydraulic shaker
This shaker, known as HYDRA, can simulate the vibrations of a major earthquake.

The ESA Intermediate eXperimental Vehicle being shaken and stirred



Vibrators
Shakers are used to put spacecraft through the intense vibrations that they will experience during launch.

Data-handling rooms
Adjacent rooms allow data to be analysed straight away, streamlining the testing process.


Foam wedges absorb sound and radio signals, creating 'anechoic' rooms

Compact Payload Test Range
This area allows satellites and other payloads to be tested in conditions that mimic those experienced in orbit.

Airlock
The entire facility is kept sealed and clean to prevent damage to the spacecraft.

Faraday cage
Metal on the walls, floors and ceilings continuously conducts electricity to screen out external radiation.

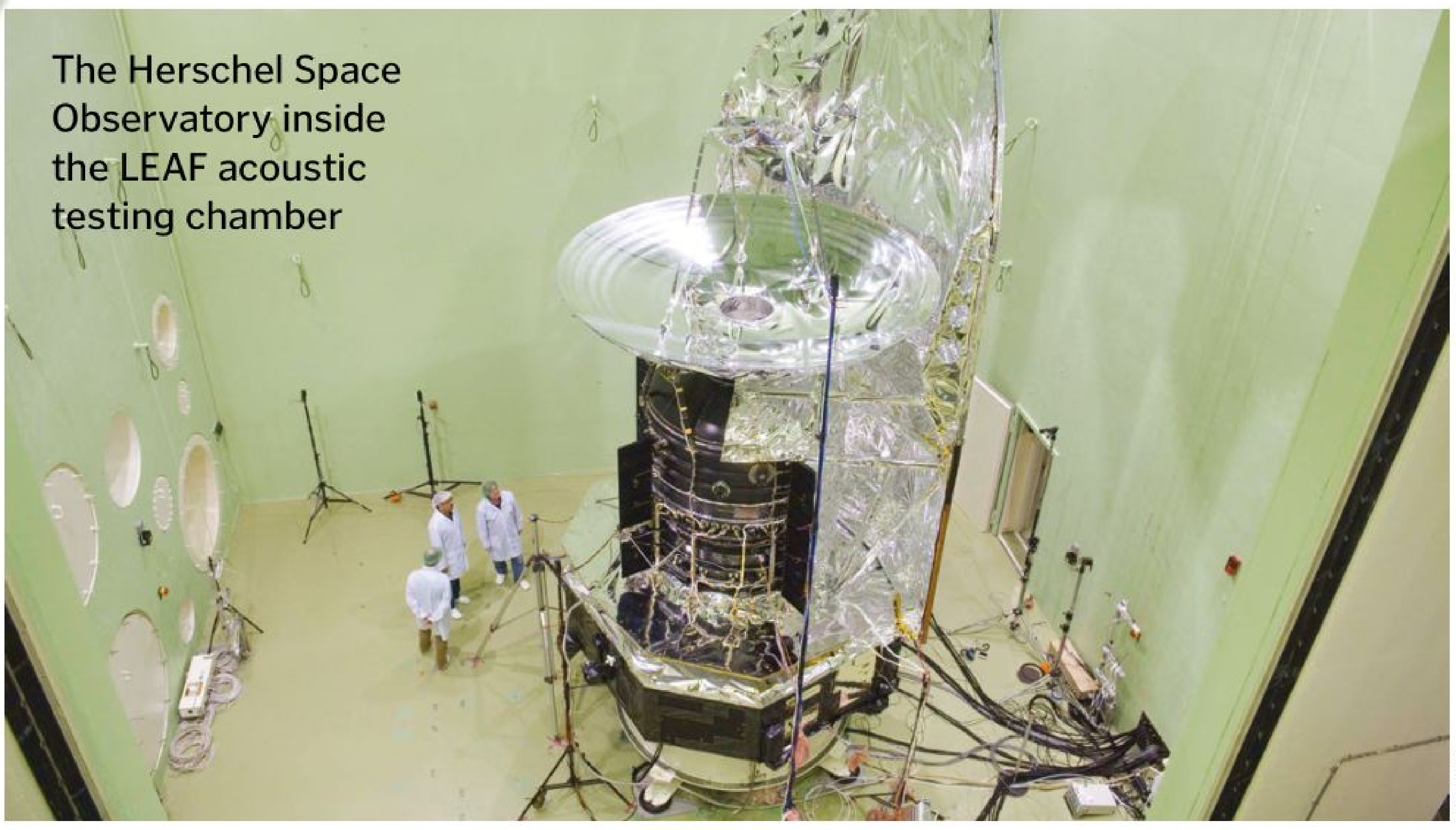
Large European Acoustic Facility
This spring-mounted, soundproofed room hits test vehicles with an intense wall of noise to simulate launch.

Sound proofing
The walls of the sound chamber are 0.5 metres thick, and made from steel-reinforced concrete to keep the sound contained.

Pushed to the limit

The Test Centre is equipped with an impressive arsenal of kit designed to test spacecraft and their payloads to breaking point. Physical properties machines weigh and measure the equipment, determining the centre of gravity and the moment of inertia. This can help to ensure that everything is balanced if the spacecraft needs to spin in flight.

Electrically powered shakers put the equipment through the intense vibrations of launch, while a hydraulic shaker is on hand for larger, heavier equipment. The Large European Acoustic Facility (LEAF) bombards satellites with intense sound, up to 156 decibels, to ensure that they will still be able to function after launch. And the most impressive room in the facility, the Large Space Simulator, plunges test equipment into a space-quality vacuum, complete with freezing temperatures and radiation that mimics the dangerous emissions of the Sun. Throughout testing, sensitive equipment gathers data about how the spacecraft are performing, ensuring that they will be ready for the real thing.


The Herschel Space Observatory inside the LEAF acoustic testing chamber

© ESA

FROM THE ARCHIVES
Originally published in 2011

The Orion spacecraft

How the replacement for NASA's Space Shuttle will take us to the moon and beyond

The primary goals of the Orion spacecraft, which has been contracted to technology company Lockheed Martin by NASA, are to deliver crew and cargo to the International Space Shuttle and return astronauts to the moon after almost a 50-year wait. Orion is scheduled to make its first test flight before 2014 and complete a lunar mission by the early 2020s.

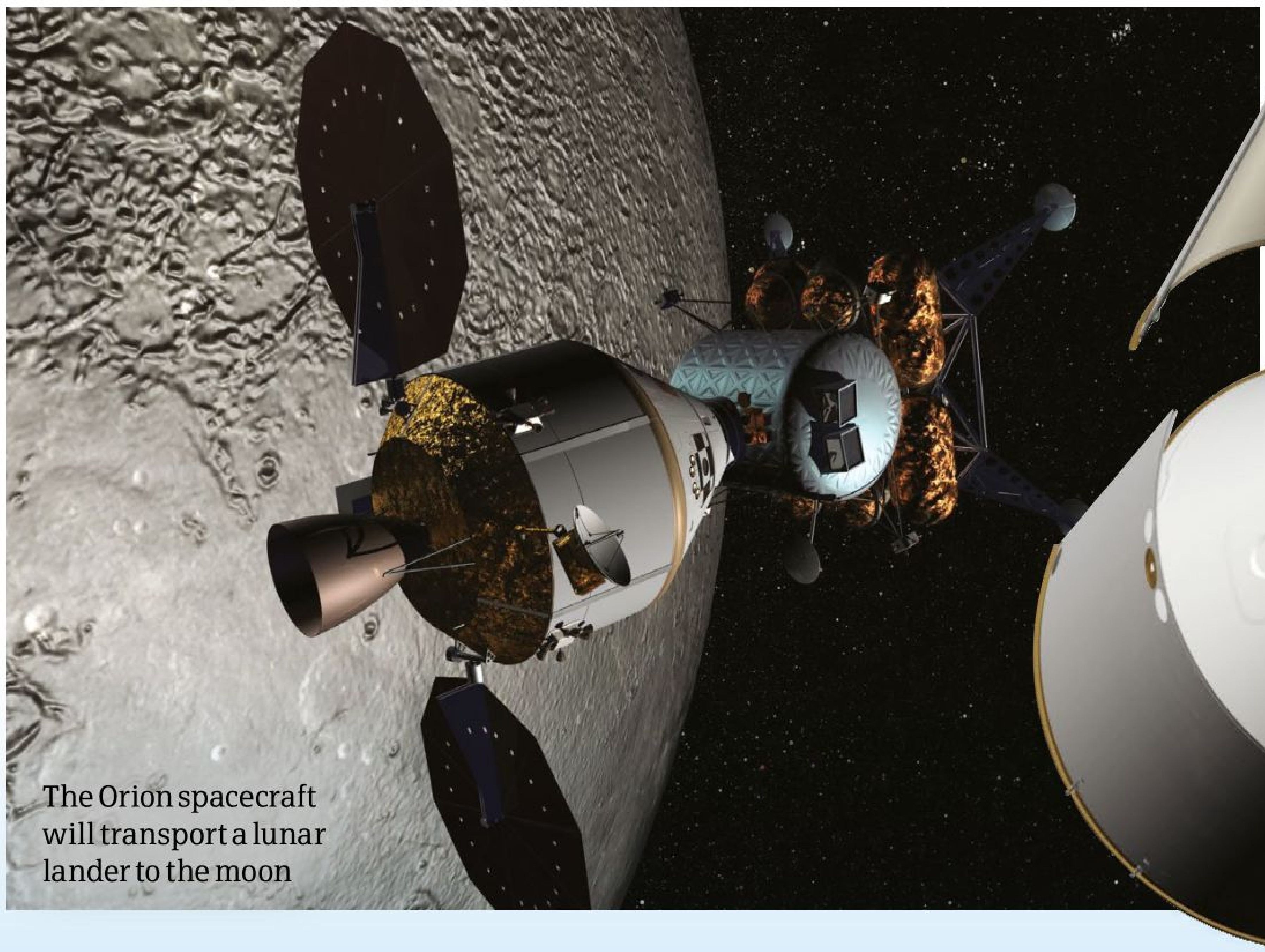
The Orion crew module is similar in design and appearance to the Apollo Command Module that first took astronauts to the moon. It is three times the volume of the Apollo module with the same 70° sloped top, deemed to be the safest and most reliable shape for re-entering Earth's atmosphere at high velocity. The Orion module has a diameter of five metres and a total mass of about 9,000kg including the cargo and the crew, which increases or decreases slightly for missions to the International Space Station and the moon respectively. Unlike the Apollo module, which had a crew capacity of three people, the Orion module can carry between four and six astronauts.

Attached to the crew module is the service module, responsible for propulsion, electrical power, communications and water/air storage. The service module is equipped with a pair of extendable solar panels that are deployed post-launch in addition to batteries to store power for times of darkness. Like the Orion crew module, the service module is also five metres in diameter to provide a clean fit between the two, and has a mass of about 3,700kg in addition to 8,300kg of propellant.

Exerting 33,000 newtons (7,500 pounds) of thrust, the engine of the service module uses hypergolic fuels monomethyl hydrazine and nitrogen tetroxide, which are propellants that ignite on contact with each other and require no ignition source. Another benefit of these propellants is that they do not need to be cooled like other fuels; they can be stored at room temperature. 24 thrusters around the service module will also give it control to change its orientation in all directions, but these are almost 30 times weaker than the main booster.

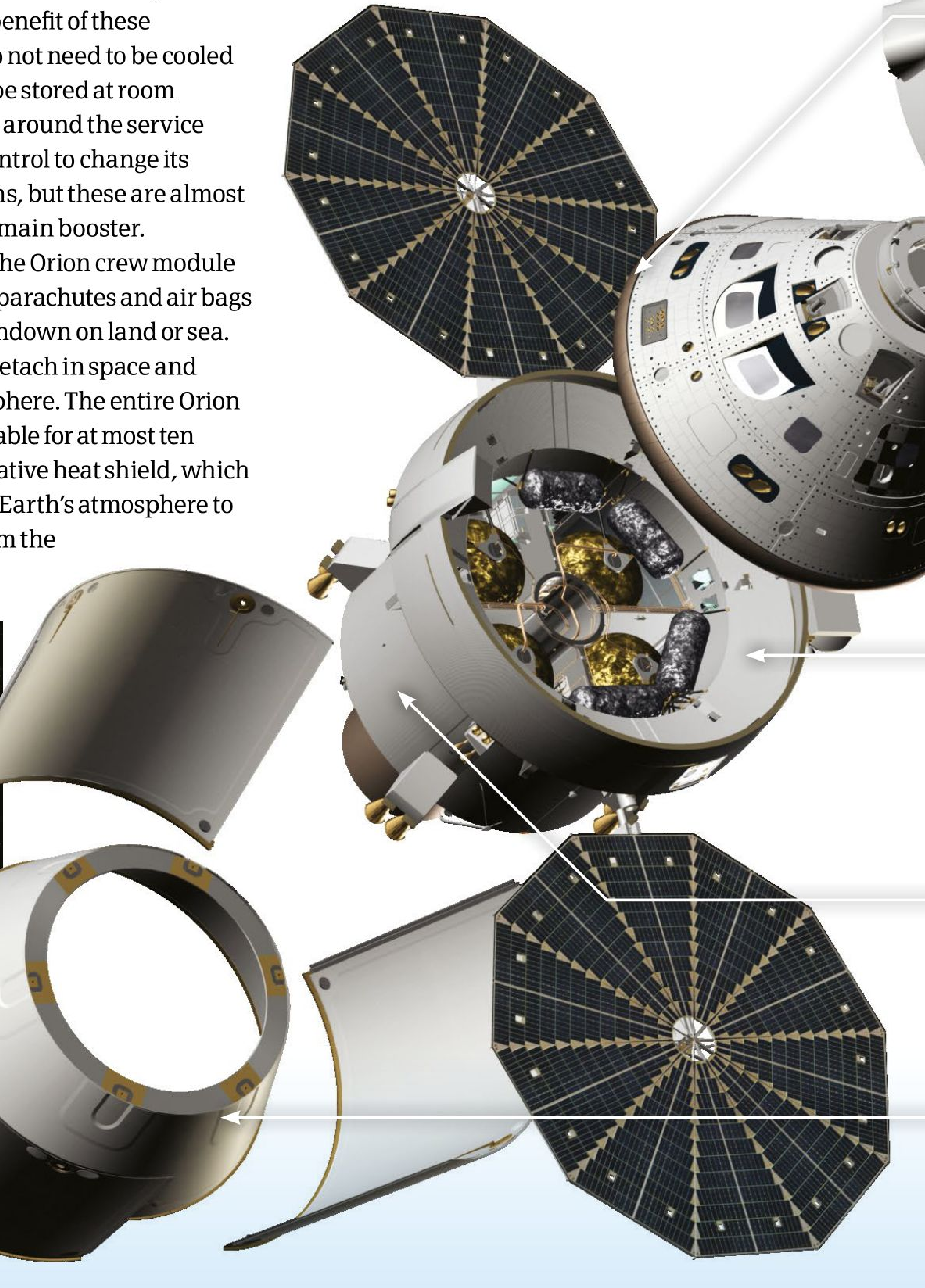
Upon descent to Earth the Orion crew module will use a combination of parachutes and air bags to allow a cushioned touchdown on land or sea. The service module will detach in space and disintegrate in the atmosphere. The entire Orion crew module will be reusable for at most ten missions except for its ablative heat shield, which burns up on re-entry into Earth's atmosphere to protect the astronauts from the extreme heat.

The first Orion missions will see it dock with the ISS to test its systems



The Orion spacecraft will transport a lunar lander to the moon

© NASA



5 TOP FACTS COMMERCIAL SPACE RACE

Orion

1 Although Orion is currently still on schedule, there are murmurs that the project could be canned in favour of using private companies for transporting crew to the ISS.

SpaceX Dragon

2 One of the competitors, the Dragon capsule is currently undergoing cargo testing and could be ready to transport crew members to the ISS as early as June 2012.

Boeing CST-100

3 After losing the Orion contract to Lockheed Martin, Boeing's capsule (similar in design to Orion) has been helped by $18m of funding from NASA and could launch by 2015.

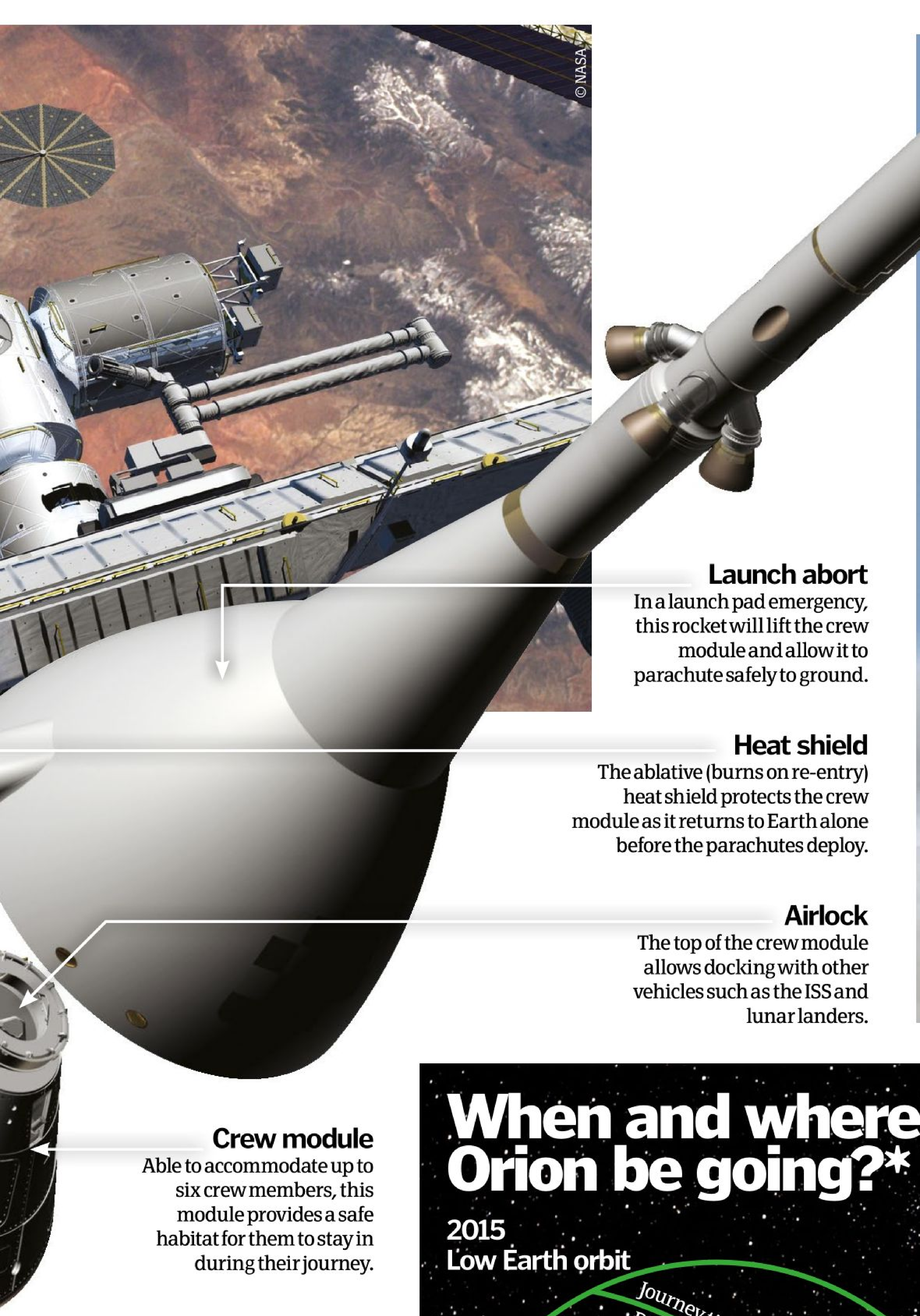
Dream Chaser

4 Under development by the Sierra Nevada Corporation, this space plane won $20m from a NASA competition. It could land on almost any runway in the world.

X-37B

5 This US military space plane returned from a seven-month orbit in December and made the first ever spacecraft landing by autopilot, but its intentions are unknown.

DID YOU KNOW? *An Orion test module will use over 150,000 ping-pong balls to stop it sinking after splashing down in the ocean*



Launch abort
In a launch pad emergency, this rocket will lift the crew module and allow it to parachute safely to ground.

Heat shield
The ablative (burns on re-entry) heat shield protects the crew module as it returns to Earth alone before the parachutes deploy.

Airlock
The top of the crew module allows docking with other vehicles such as the ISS and lunar landers.

Crew module
Able to accommodate up to six crew members, this module provides a safe habitat for them to stay in during their journey.

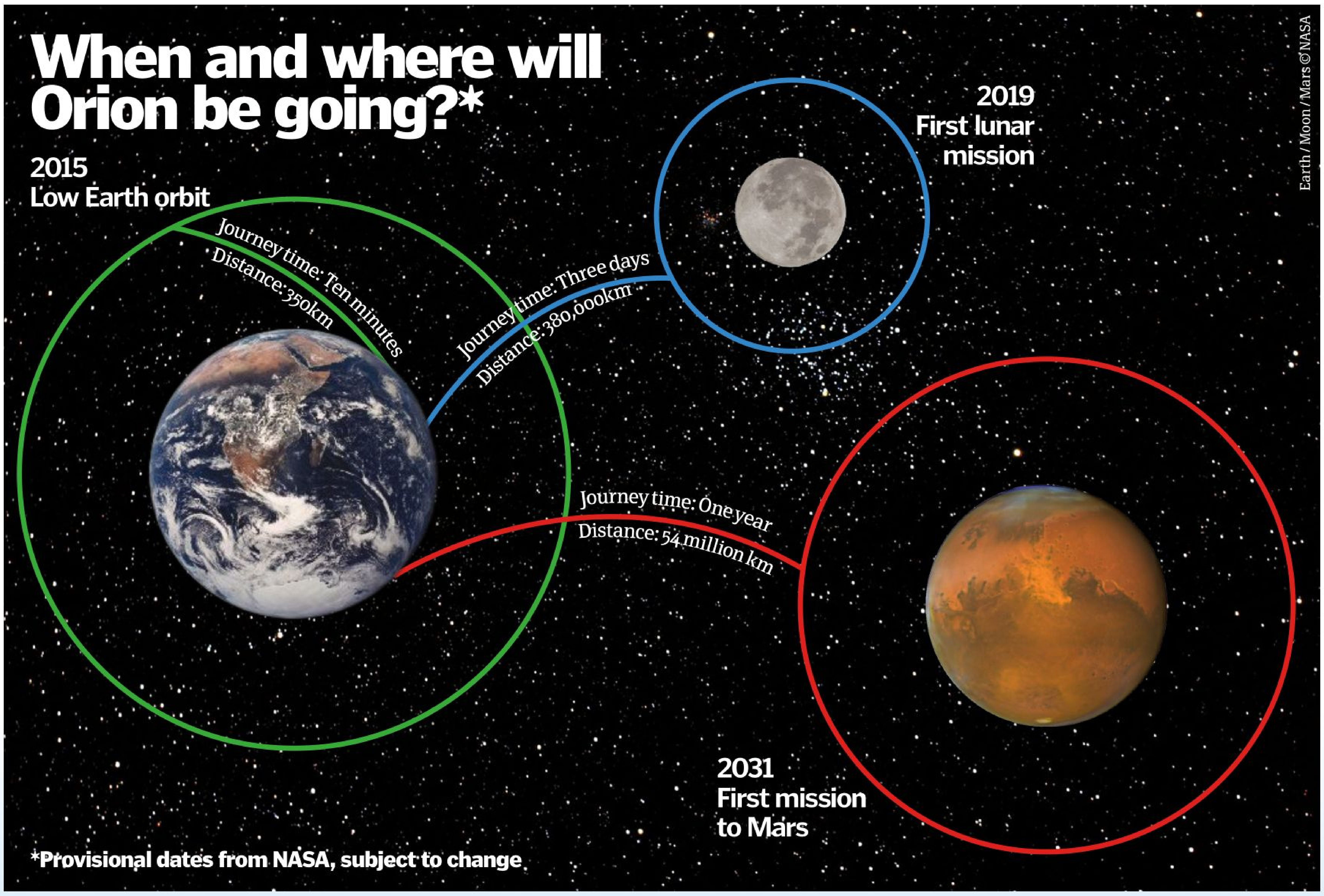
Service module
This module supports the crew throughout their journey, providing life support and propulsion, before detaching upon Earth re-entry.

Cargo
Inside the service module, unpressurised cargo for the ISS and science equipment are stored.

Spacecraft adapter
Connects the Orion spacecraft to the launch rocket, and also protects components in the service module.

The Launch Abort System will carry the crew module to safety in an emergency

When and where will Orion be going?*


2015
Low Earth orbit
Journey time: Ten minutes
Distance: 350km
2019
First lunar mission
Journey time: Three days
Distance: 380,000km
Journey time: One year
Distance: 54 million km
2031
First mission to Mars
Earth / Moon / Mars © NASA

*Provisional dates from NASA, subject to change

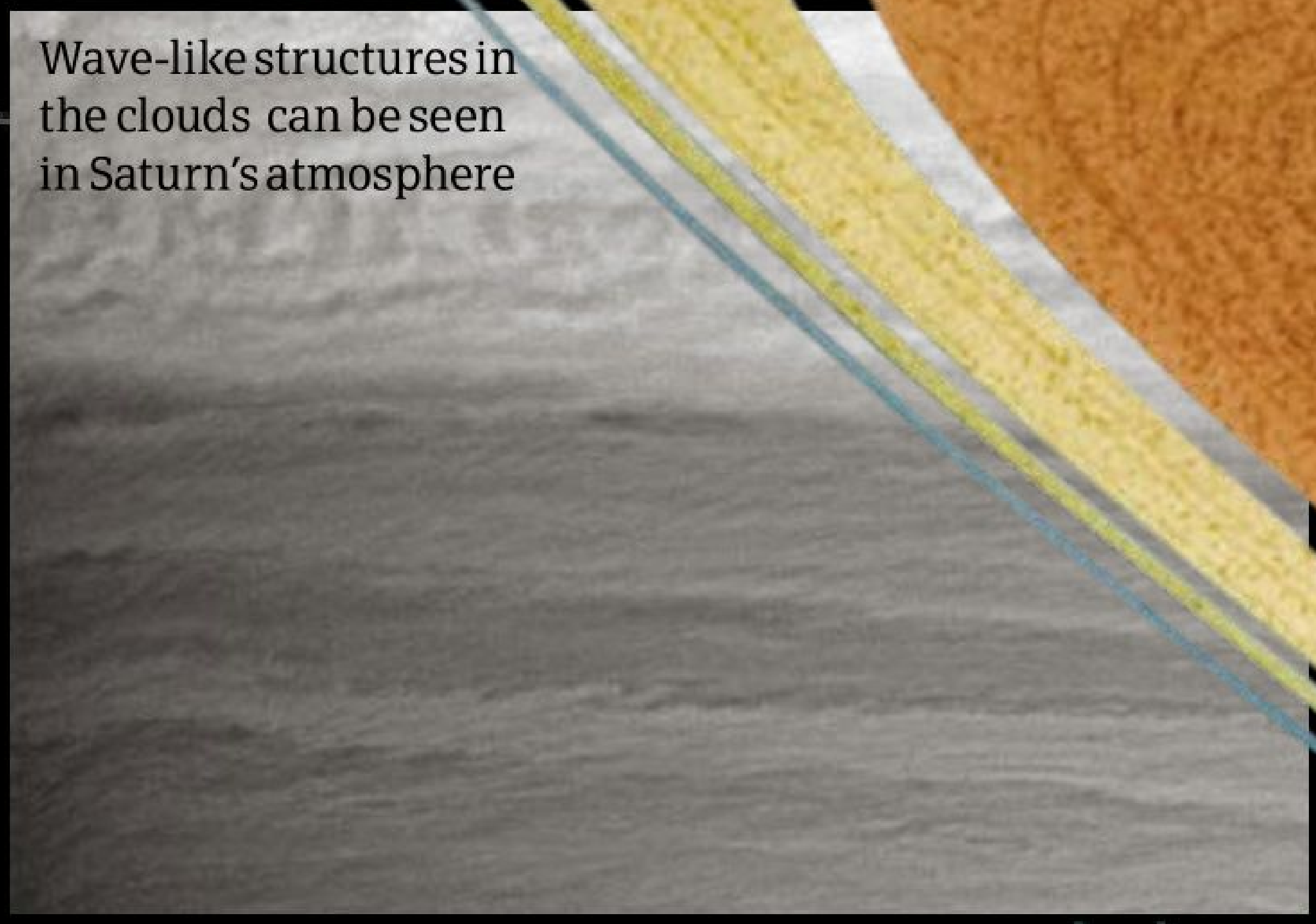
Saturn

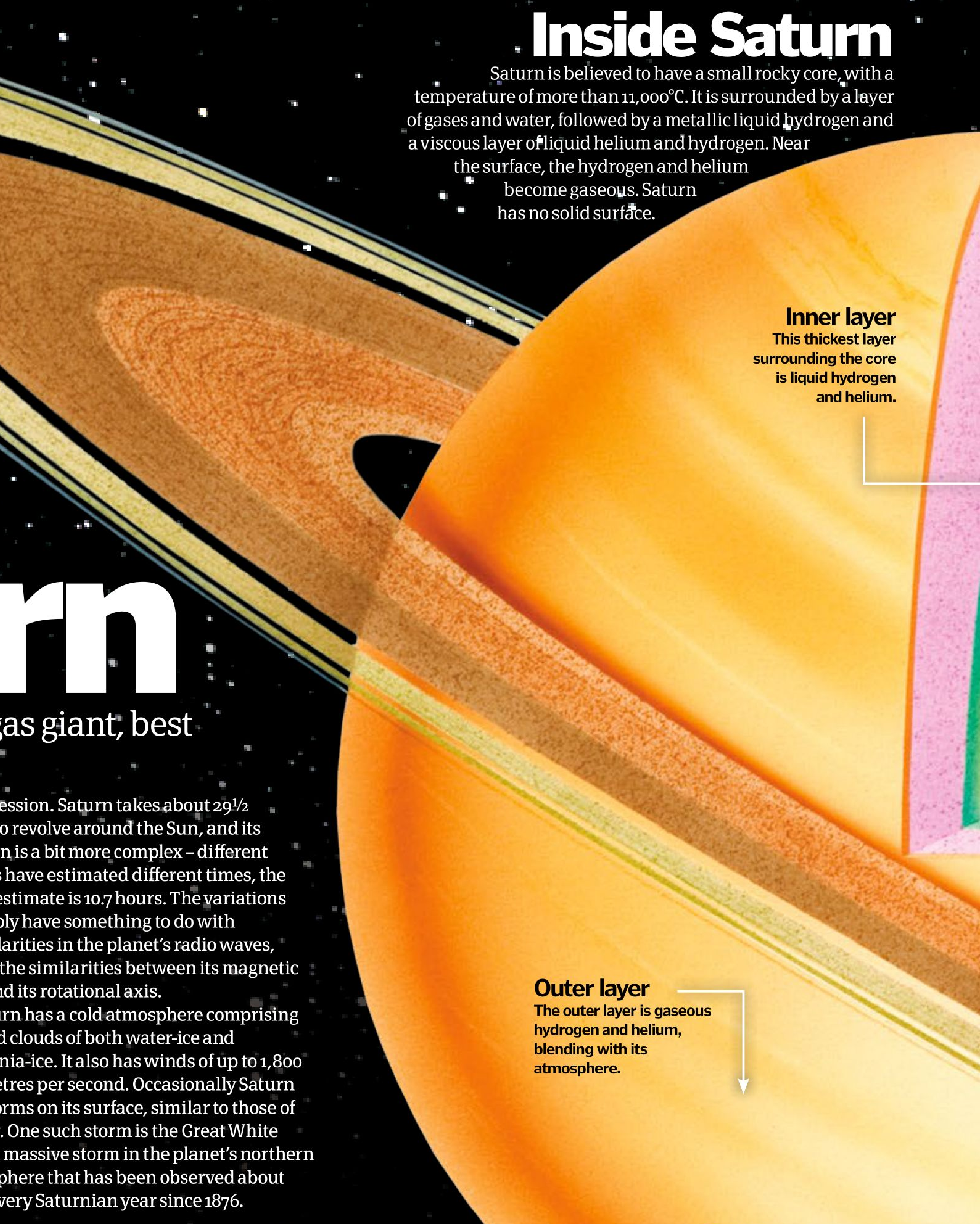
Only Jupiter is larger than this gas giant, best known for its ring system

We've been viewing Saturn with the naked eye since prehistoric times, but the planet's most unique feature – its ring system – wasn't discovered until 1610. Each ring contains billions of chunks of dust and water-ice. Saturn has about 14 major ring divisions, but there are also satellites and other structures within some of the rings and gaps. Saturn's rings are believed to have come from the remains of moons, comets or other bodies that broke up in the planet's atmosphere.

The rings aren't the only fascinating thing about Saturn, however. This gas giant is less dense than any other planet in our solar system and has a mostly fluid structure. It radiates a massive amount of energy, thought to be the result of slow gravitational compression. Saturn takes about 29½ years to revolve around the Sun, and its rotation is a bit more complex – different probes have estimated different times, the latest estimate is 10.7 hours. The variations probably have something to do with irregularities in the planet's radio waves, due to the similarities between its magnetic axis and its rotational axis.

Saturn has a cold atmosphere comprising layered clouds of both water-ice and ammonia-ice. It also has winds of up to 1,800 kilometres per second. Occasionally Saturn has storms on its surface, similar to those of Jupiter. One such storm is the Great White Spot, a massive storm in the planet's northern hemisphere that has been observed about once every Saturnian year since 1876.


Wave-like structures in the clouds can be seen in Saturn's atmosphere



Inside Saturn

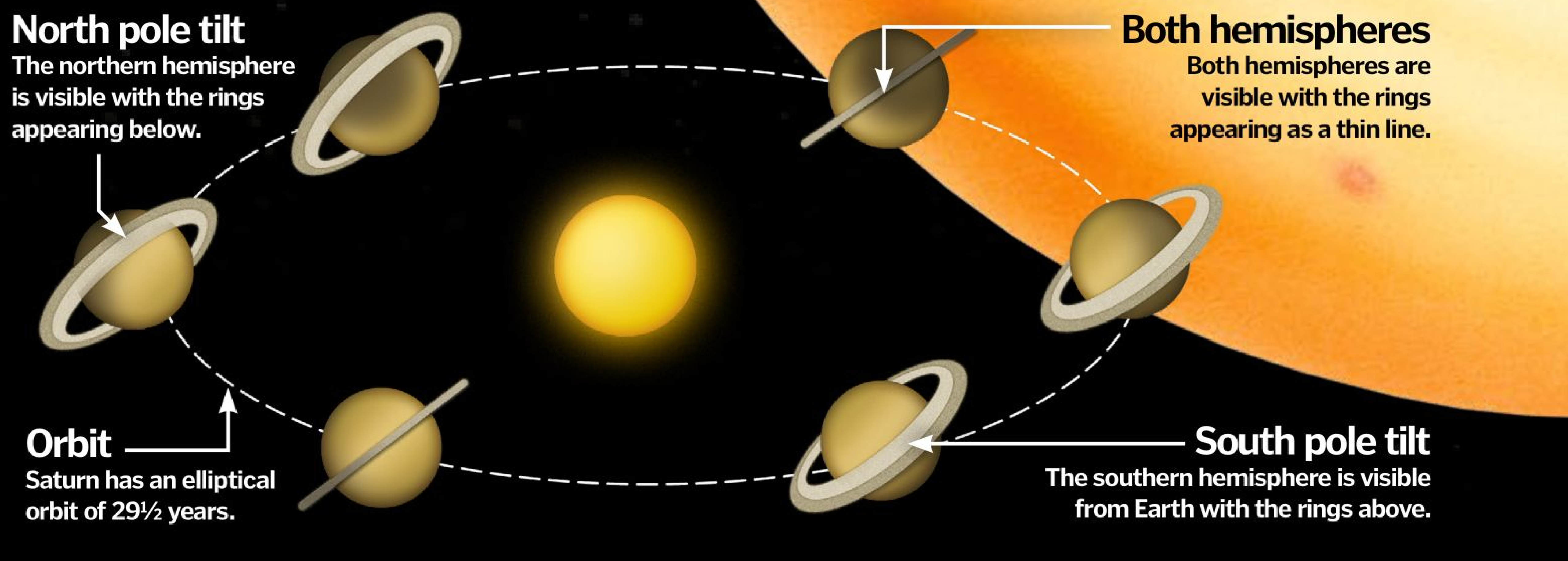
Saturn is believed to have a small rocky core, with a temperature of more than 11,000°C. It is surrounded by a layer of gases and water, followed by a metallic liquid hydrogen and a viscous layer of liquid helium and hydrogen. Near the surface, the hydrogen and helium become gaseous. Saturn has no solid surface.

Inner layer
This thickest layer surrounding the core is liquid hydrogen and helium.

Outer layer
The outer layer is gaseous hydrogen and helium, blending with its atmosphere.

Rings in view

Saturn takes 29½ years to orbit the Sun, and it has an elliptical orbit like most planets. The closest Saturn comes to the Sun is 1.35 billion kilometres, while at its furthest, Saturn is 1.5 billion kilometres away. Saturn has a tilt of 26.7 degrees relative to the orbital plane. During half of its orbital period, the northern hemisphere is facing the Sun, while the southern hemisphere faces the Sun during the other half. When viewing Saturn from Earth, this impacts whether we can see the rings full-on or as a thin line.



North pole tilt
The northern hemisphere is visible with the rings appearing below.

Both hemispheres
Both hemispheres are visible with the rings appearing as a thin line.

Orbit
Saturn has an elliptical orbit of 29½ years.

South pole tilt
The southern hemisphere is visible from Earth with the rings above.

DID YOU KNOW?

Discovering the rings

Galileo thought that he was seeing moons orbiting Saturn instead of rings because his telescope was not powerful enough. Astronomer Christiaan Huygens observed the rings in 1655, but thought they were a single ring.

DID YOU KNOW? *Images from the Cassini probe show that Saturn has a bright blue northern atmosphere*

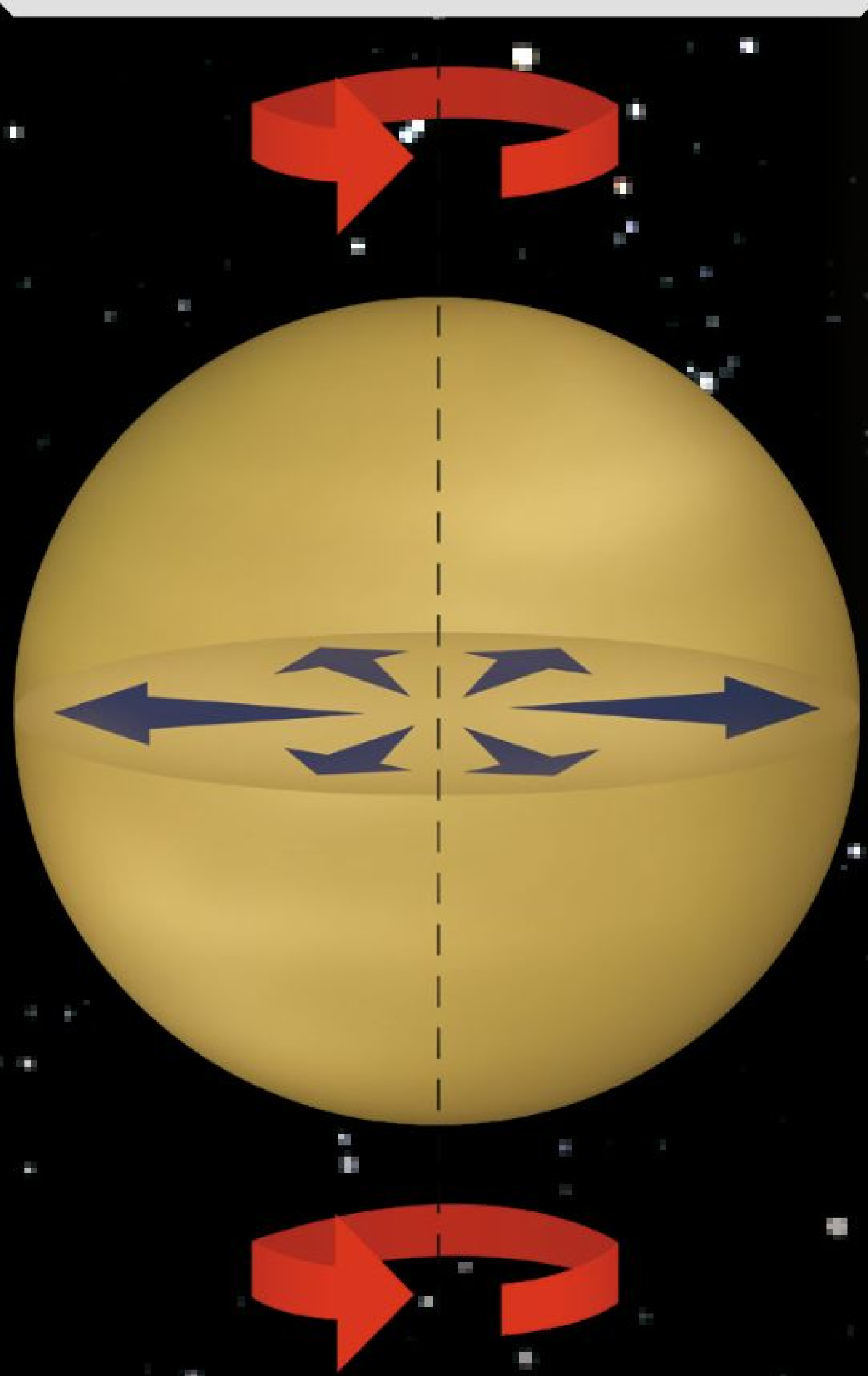
The Statistics

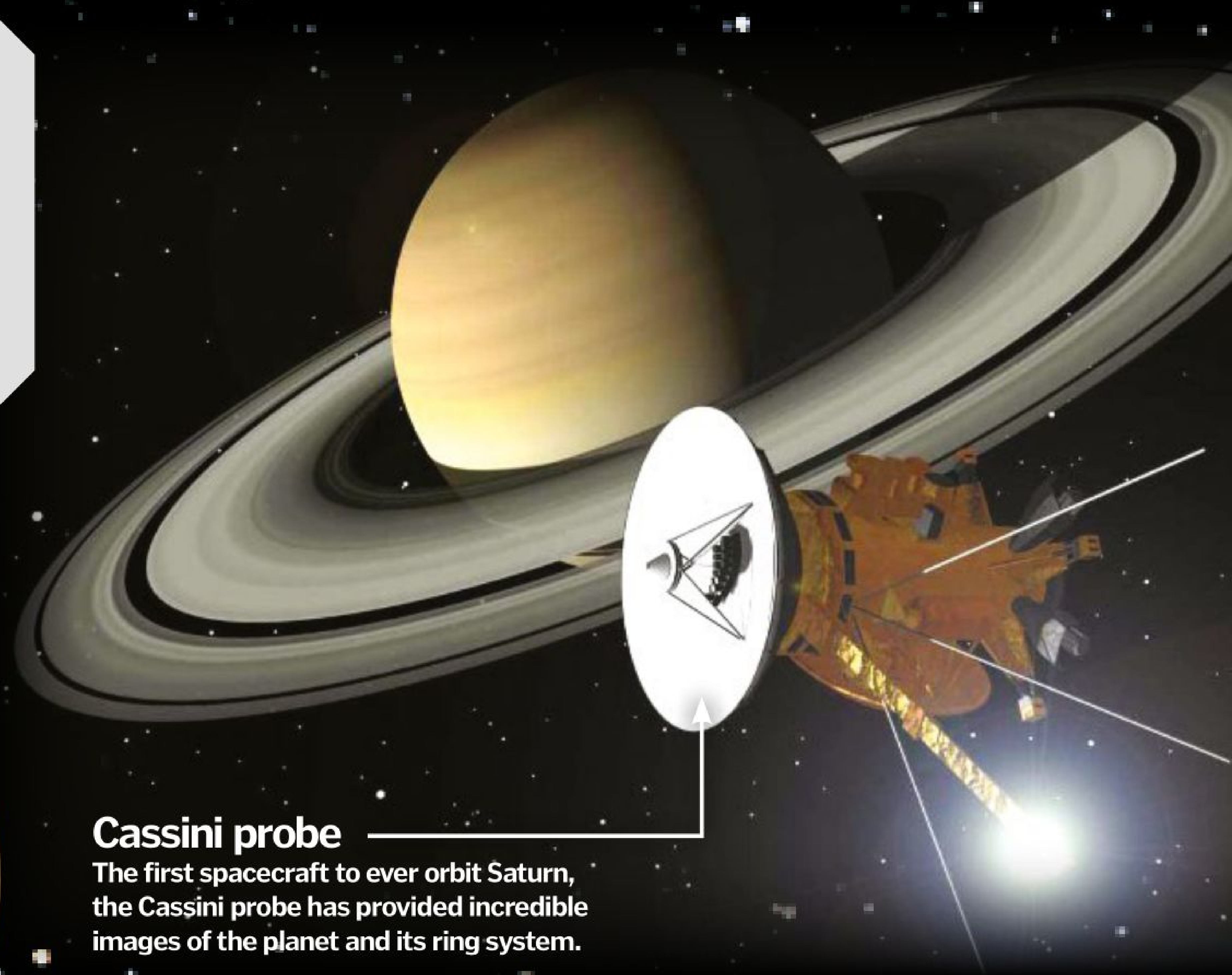
Saturn

Diameter: 120,535 km
Mass: 5.6851 x 10^{26} kg
Density: 0.687 grams per cm^3
Average surface temperature: -139°C
Core temperature: 11,000°C
Moons: 62
Average distance from the Sun: 1,426,725,400km
Surface gravity: 10.44 metres per second squared

Extreme bulge

Saturn is an extreme example of an oblate spheroid – the difference between the radius of the planet at its poles and at its circumference is about ten per cent. This is due to its very short rotational period of just over ten hours.

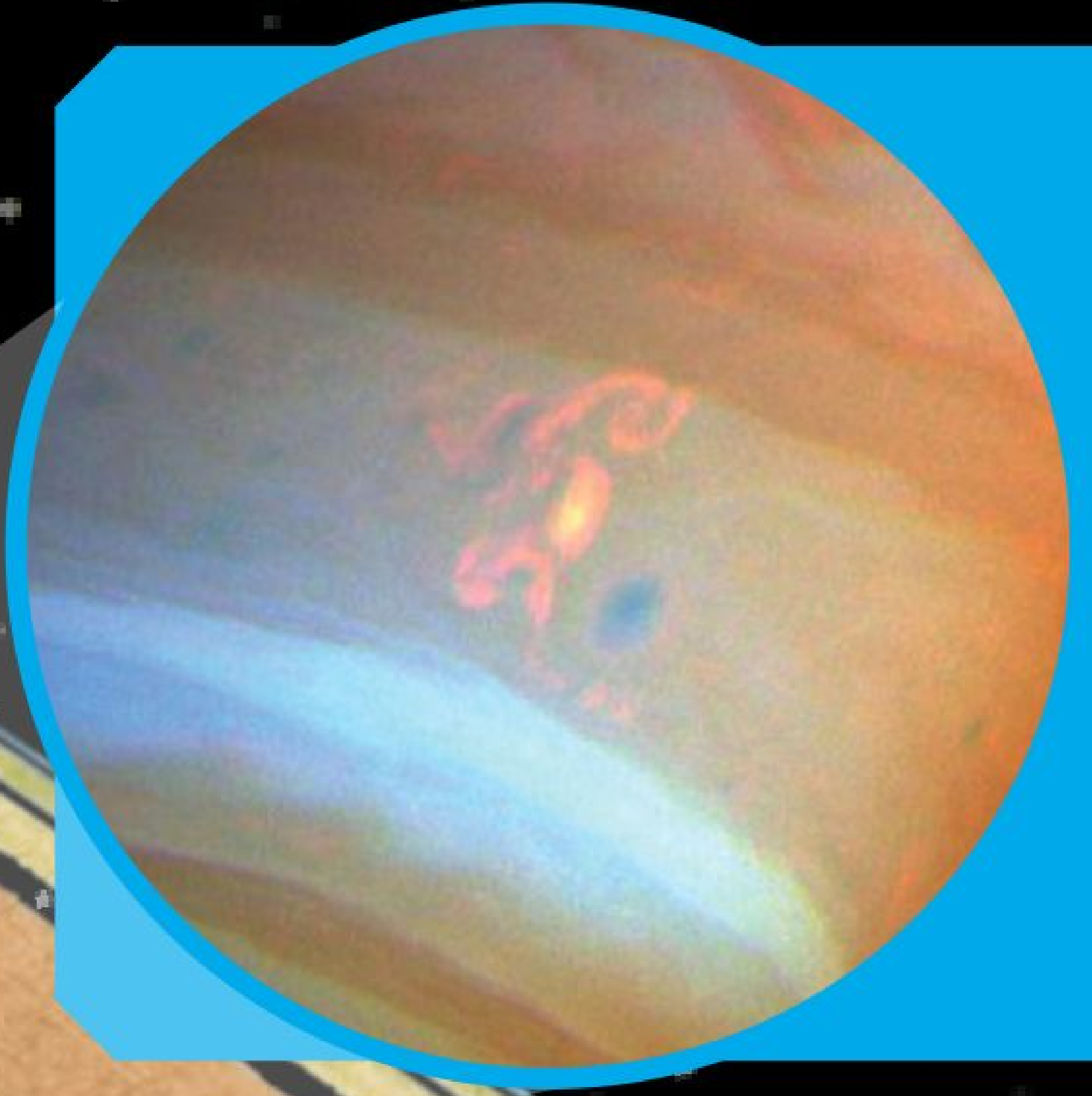




Cassini probe
The first spacecraft to ever orbit Saturn, the Cassini probe has provided incredible images of the planet and its ring system.

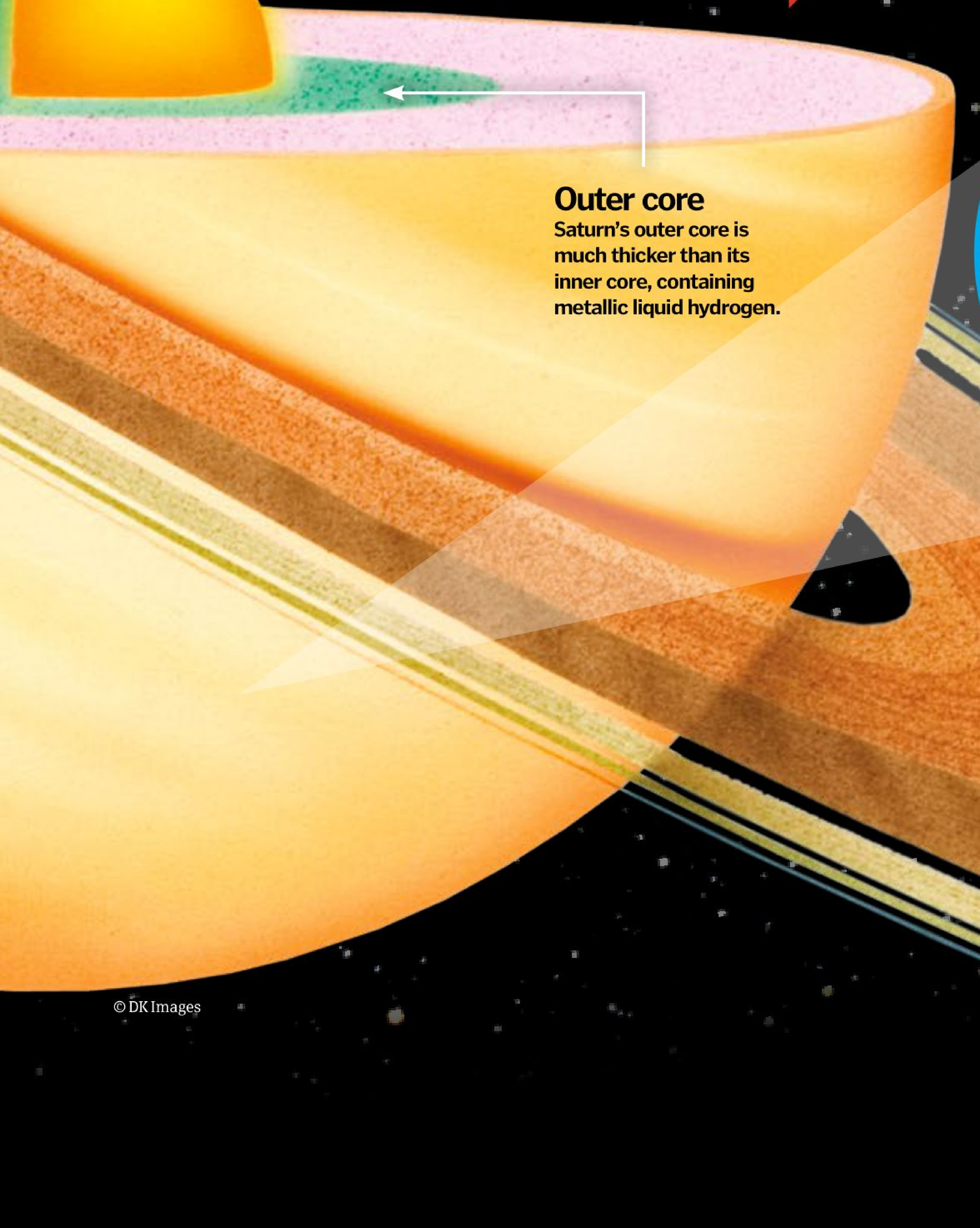
Float that planet

If we had a big enough pond, we could float Saturn on its surface. Although Saturn is the second-largest planet as well as the second-most massive, it's the least-dense planet in our solar system. Its density is just 0.687 grams per cubic centimetre, about one-tenth as dense as our planet and two-thirds as dense as water.



Saturn's southern storm

In 2004, the Cassini space probe discovered a massive, oddly shaped convective thunderstorm in Saturn's southern atmosphere. Dubbed the Dragon Storm, this weather feature emitted strong radio waves. Like storms on Earth, the Dragon Storm emits flashes of lightning that appear as white plumes. Scientists believe it exists deep in the atmosphere and can occasionally flare up.

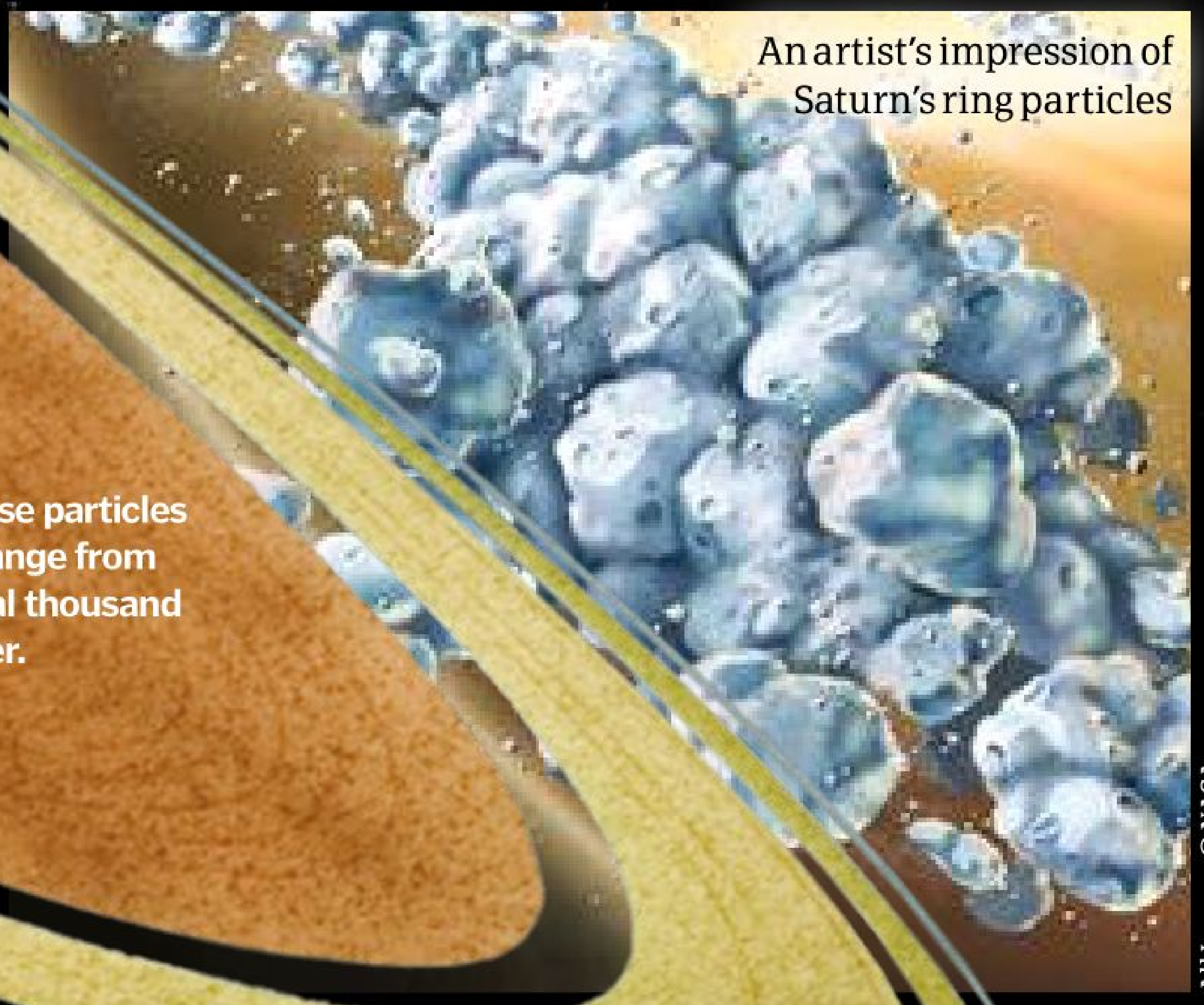


Inner core
The inner core is likely very small and contains silicate rock, much like Jupiter's core.

Outer core
Saturn's outer core is much thicker than its inner core, containing metallic liquid hydrogen.

Rings
Saturn's rings comprise particles of ice and dust that range from microscopic to several thousand kilometres in diameter.

© DK Images



An artist's impression of Saturn's ring particles

All Images © NASA

Neutron stars

These remnants of supernovae are some of the most massive objects in the universe

A neutron star sits at the centre of the Crab Nebula

© NASA

A star with a mass of less than 1.5 solar masses (the mass of the Sun) forms a white dwarf at the end of its lifetime, owing to its gravity being too weak to collapse it further. If the mass of a star is greater than five solar masses, the forces will be so intense that the star collapses past the point of a neutron star and becomes a black hole. However, between these two extremes a neutron star will form as the result of a supernova, although only approximately one in a thousand stars will become one.

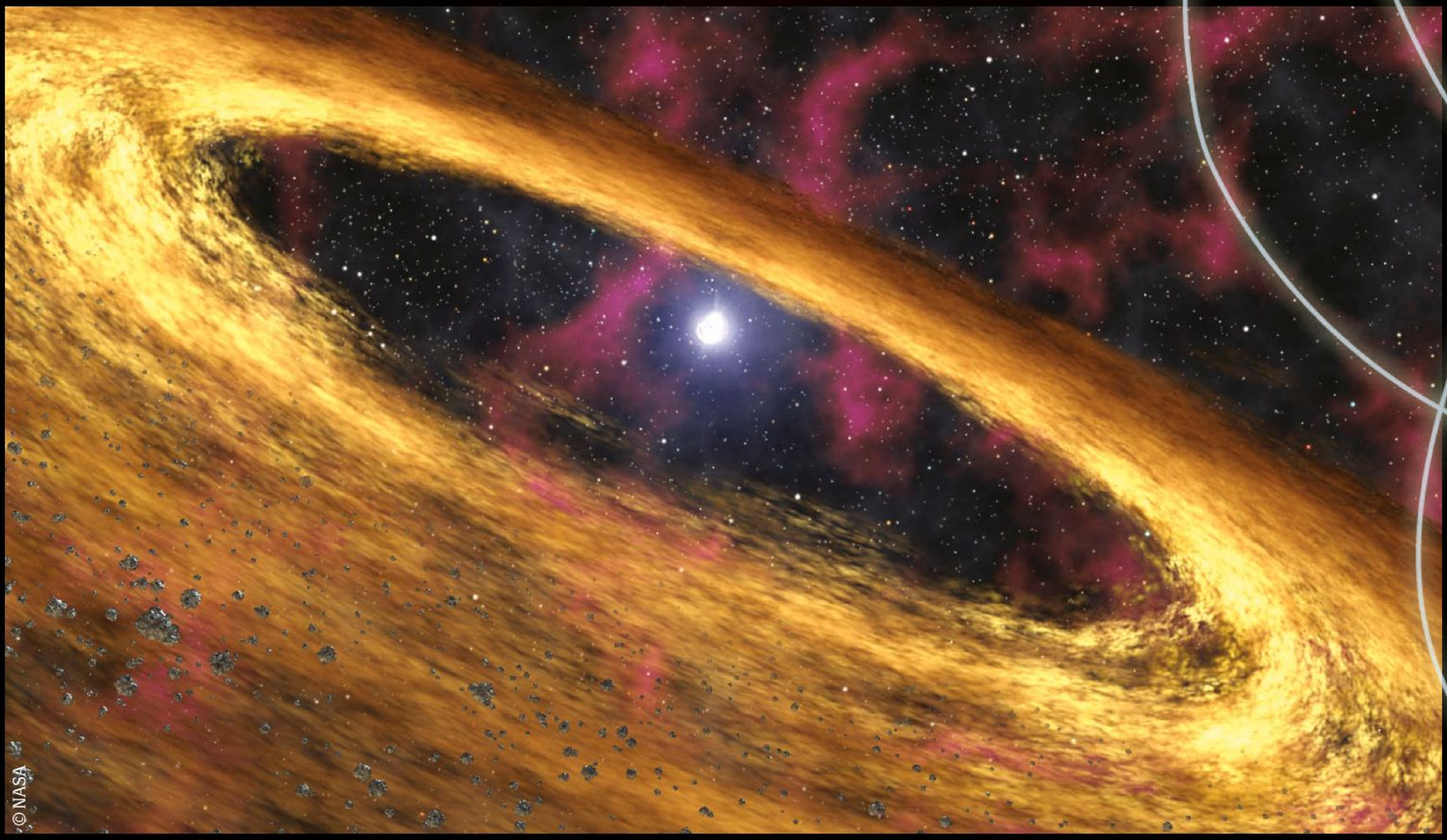
As a star runs out of fuel it will eventually collapse in upon itself. In the formation of a neutron star, the protons and electrons within every atom are forced together, forming neutrons. Material that is falling to the centre of the star is then crushed by the intense gravitational forces in the star and forms this same neutron material.

Like the Earth, magnetic fields surround neutron stars and are tipped at the axis of rotation, namely the north and south poles. However, the magnetic field of a neutron star is more than a trillion times stronger than that of Earth's.

The gravitational forces in a neutron star are also incredibly strong. The matter is so densely packed together into a radius of 12 miles (20km) that one teaspoon of mass would weigh up to a billion tons, about the same as a mountain. They also spin up to 600 times per second, gradually slowing down as they age.

Oddly enough, as a neutron star gets heavier it also gets smaller. This is because a greater mass means a greater force of gravitational attraction, and therefore the neutrons are squeezed more densely together. In fact, if you were able to drop an object from a height of one metre on the surface of a neutron star, it would hit the ground at about 1,200 miles (2,000km) per second.

Supernovae can leave neutron stars as remnants



© NASA

DID YOU KNOW?

© ESO

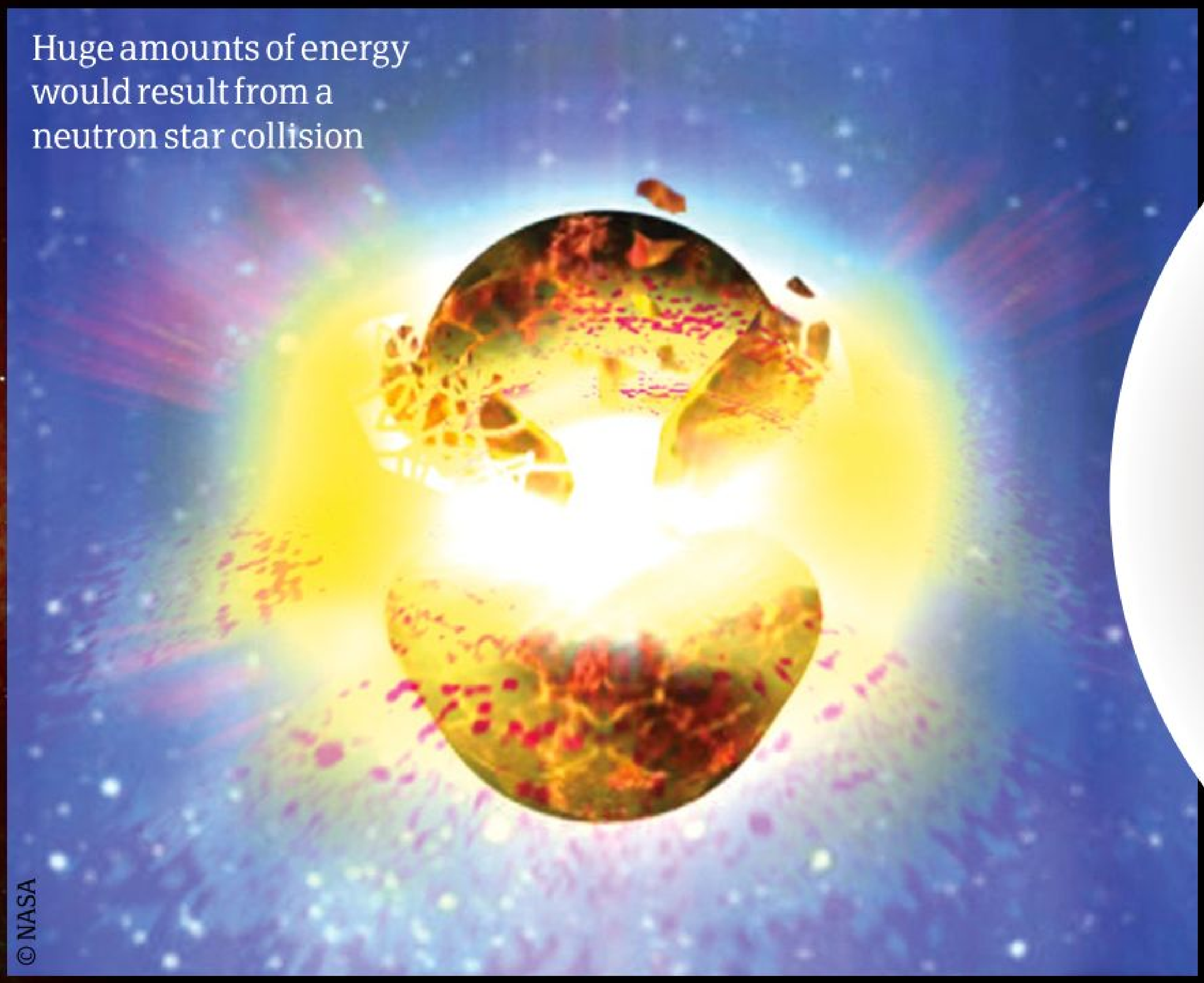
Magnetar

A neutron star with an extraordinarily large magnetic field is known as a magnetar. Small 'glitches' in the magnetic field of a magnetar can cause giant stellar quakes, one of the largest known explosions in the universe.

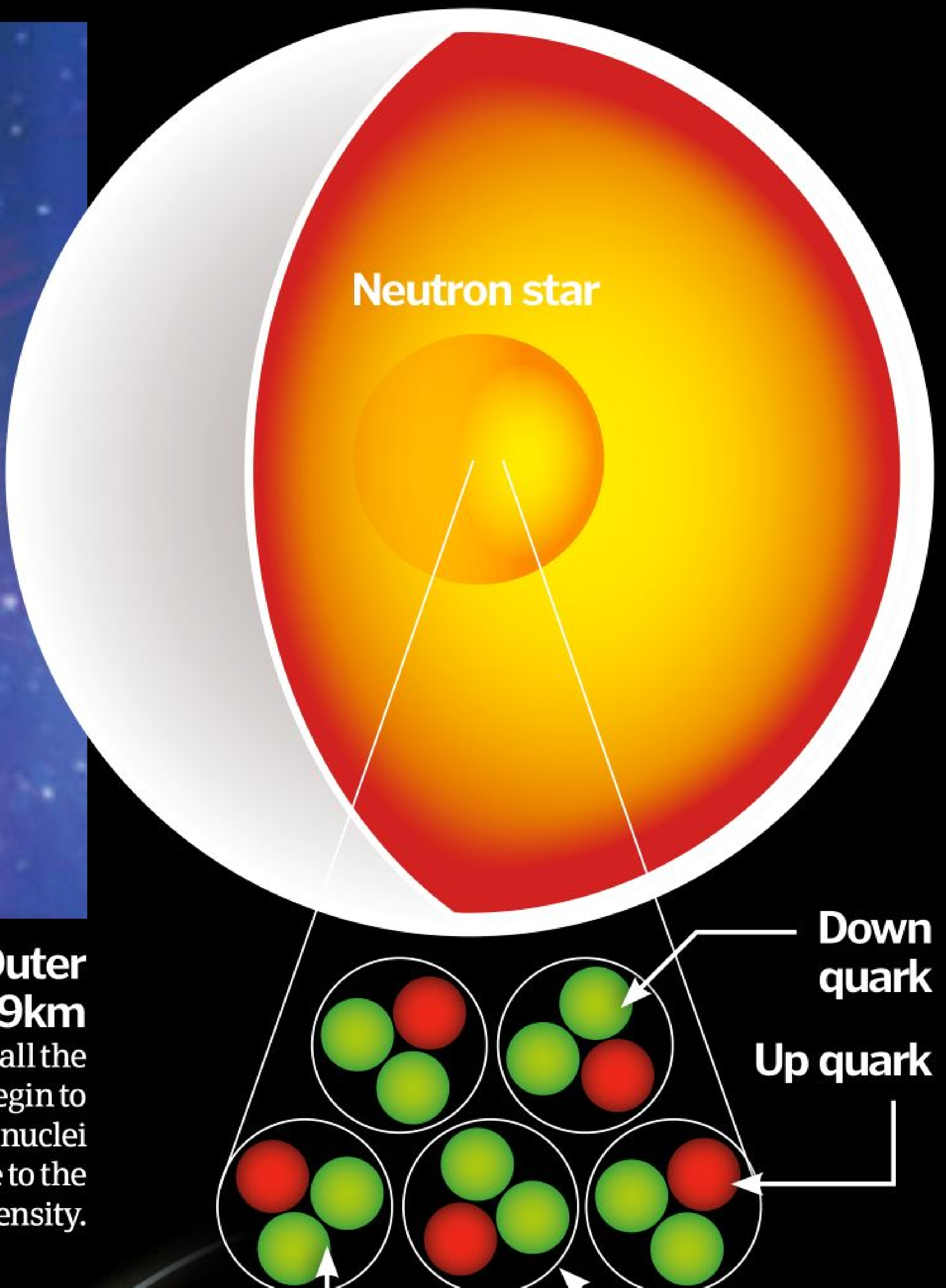
DID YOU KNOW? *The revolution of a neutron star can be so fast that its surface rotates at about 18,640 miles per second*

Inside a neutron star

The interior of a neutron star contains some very complex physics that scientists are only now beginning to understand. The conditions are unlike anything found elsewhere in the universe, making neutron stars a unique and fascinating object to examine.


Huge amounts of energy would result from a neutron star collision

© NASA

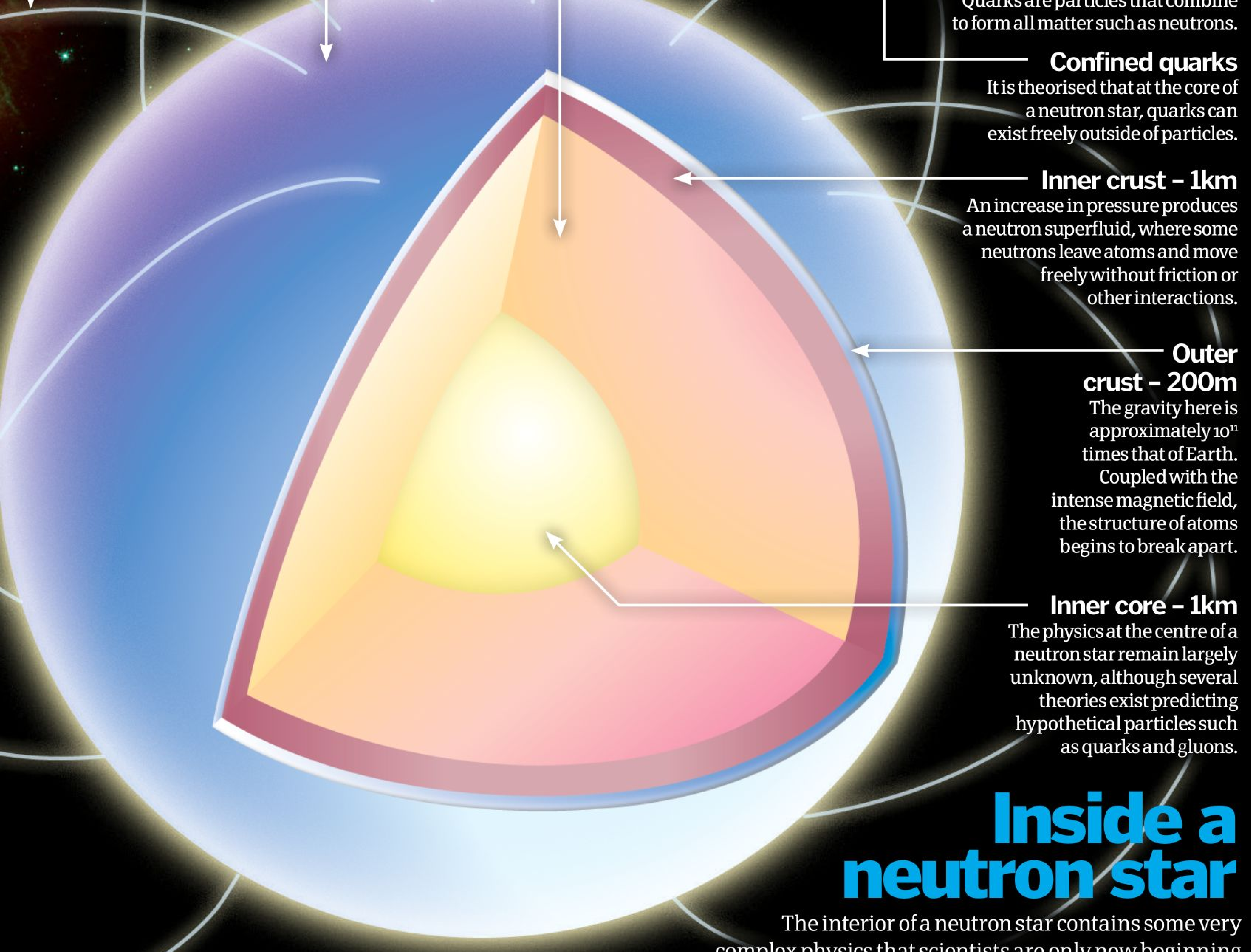


Down quark

Up quark

Neutrons
Quarks are particles that combine to form all matter such as neutrons.

Confined quarks
It is theorised that at the core of a neutron star, quarks can exist freely outside of particles.



Magnetic field lines
The strongest magnetic fields in the known universe surround a neutron star, partly responsible for breaking up the atoms in its interior.

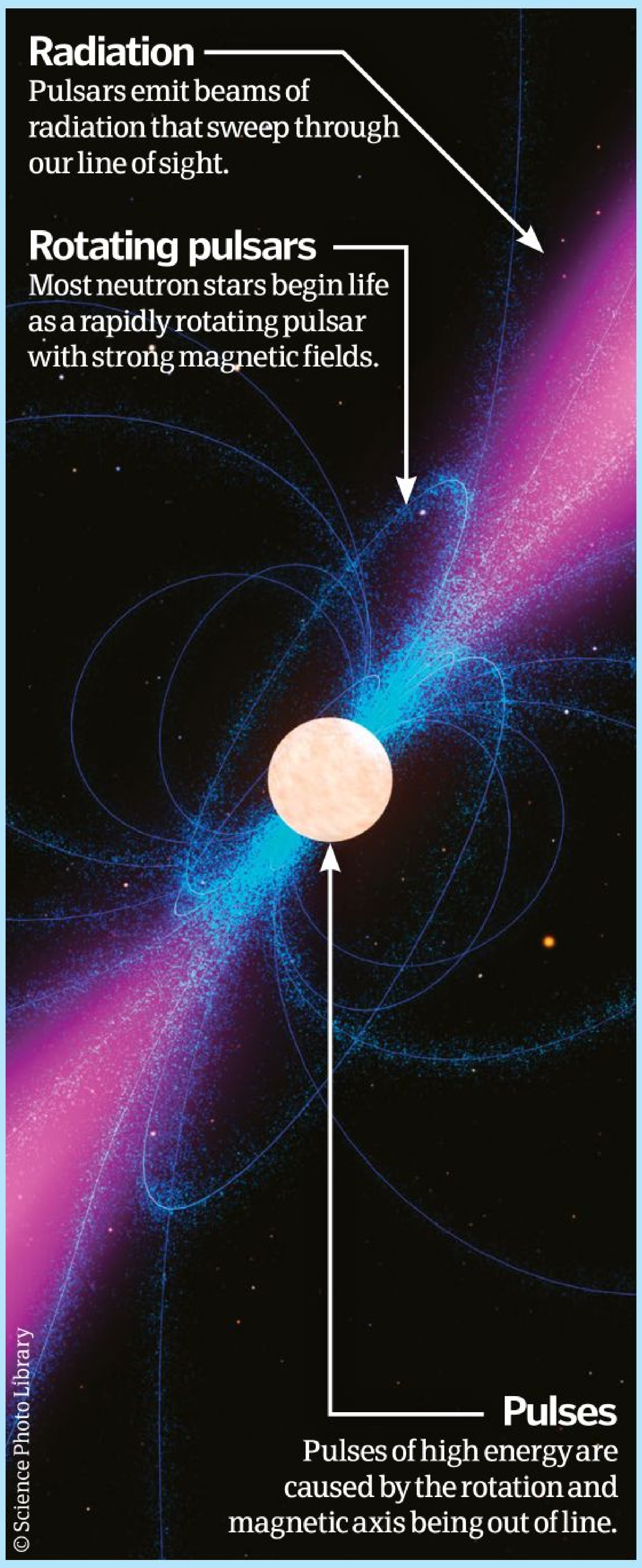
Surface
At more than 1,000,000,000°C, iron and lighter elements are present on the surface but neutron formation has not yet begun.

Outer core – 9km
Here almost all the neutrons begin to float out of the nuclei of atoms due to the very high density.

Inner crust – 1km
An increase in pressure produces a neutron superfluid, where some neutrons leave atoms and move freely without friction or other interactions.

Outer crust – 200m
The gravity here is approximately 10^{11} times that of Earth. Coupled with the intense magnetic field, the structure of atoms begins to break apart.

Inner core – 1km
The physics at the centre of a neutron star remain largely unknown, although several theories exist predicting hypothetical particles such as quarks and gluons.



Radiation
Pulsars emit beams of radiation that sweep through our line of sight.

Rotating pulsars
Most neutron stars begin life as a rapidly rotating pulsar with strong magnetic fields.

Pulses
Pulses of high energy are caused by the rotation and magnetic axis being out of line.

© Science Photo Library

Pulsars

A rapidly rotating neutron star that emits jets of particles and a large amount of electromagnetic energy (such as x-rays and light) is known as a pulsar. All neutron stars begin life as a pulsar, but as they age and lose rotational energy they are no longer considered a pulsar. The jets of electromagnetic radiation are fired out from the north and south poles of the pulsar. The gravitational force of a pulsar is so strong that apart from at the poles, matter and even light are not able to escape from its surface.

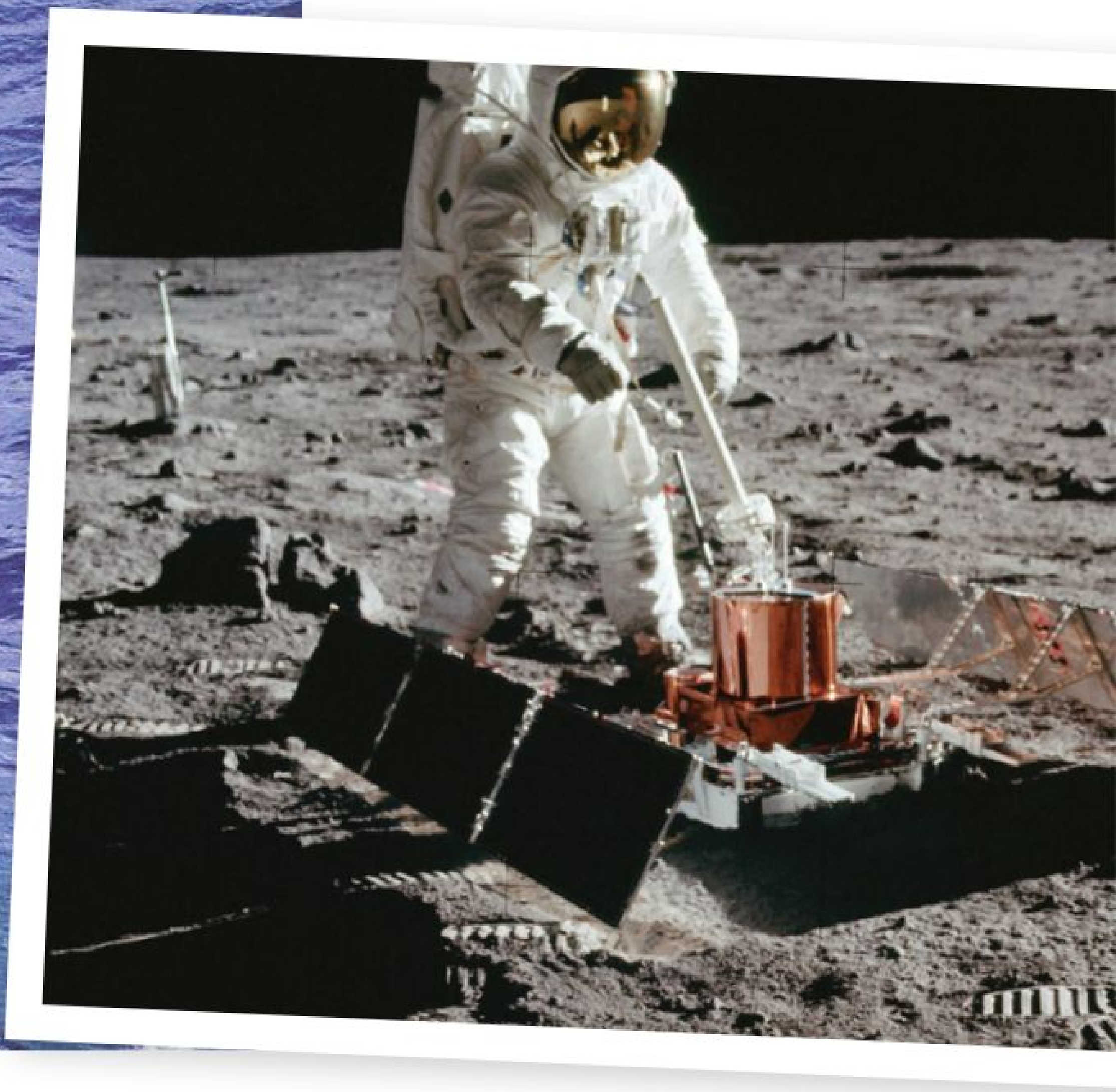
Pulsars can rotate up to 1,000 times per second, although some spin much faster. Their rate of rotation is so regular that they are the most accurate record of time in the universe; no clock on Earth can replicate their accuracy. We observe pulsars as their emitted radiation sweeps through our line of sight. Their high rotation speeds are due to a misalignment of their rotation and magnetic axis, sending them into an uncontrollable but regular spin.

Anatomy of the Apollo-Saturn V Moon rocket

It was made of around 3 million separate parts: here are some of the most important ones

The Command Module floating in the Pacific Ocean after splashdown

© NASA



The astronauts found time to deploy a few science experiments, such as this seismometer

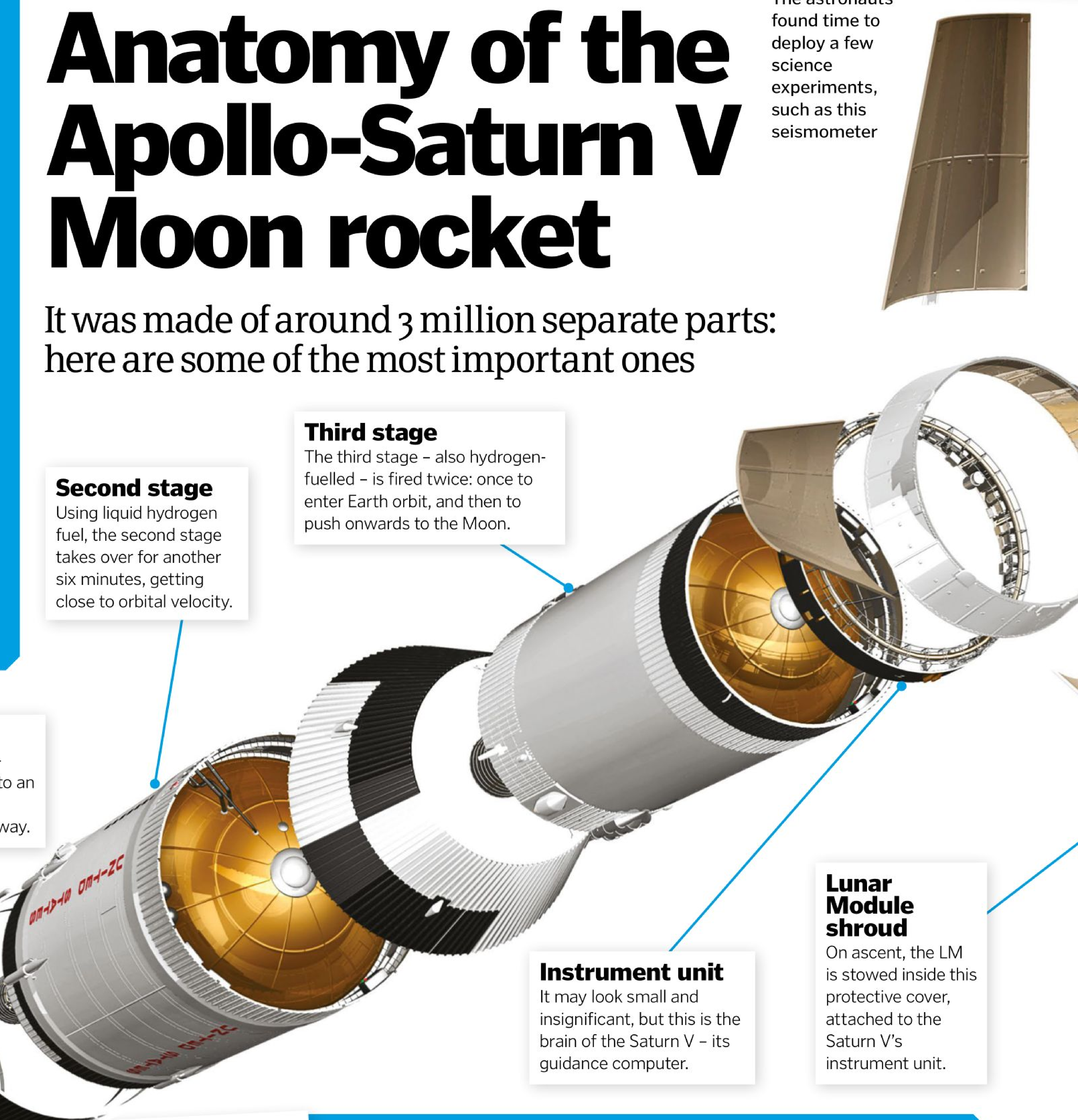
What happened to gravity?

Gravity is the main driving force in getting to the Moon, yet one of the most familiar features of spaceflight is the 'zero-g' environment – the way astronauts lose all sensation of weight. How do you reconcile these two facts? As paradoxical as it sounds, the second follows from the first. When an object moves freely in a gravitational field – whether it's falling to Earth, or in orbit around it, or en route to the Moon – it's effectively weightless. If you find that idea difficult, don't worry – Einstein did too. He puzzled over it for years, and when he finally worked it out the result was his famous theory of general relativity.

As the astronauts landed on the Moon, they experienced weight again – but only at a sixth of its strength on Earth. Gravitational fields are generated by mass, and the Moon is much less massive.

© Getty

Apollo 10 astronauts Thomas Stafford and John Young demonstrate weightlessness



© Science Photo Librar

Main engines
A cluster of five rocket engines, each over five metres tall, are needed to lift the near 3,000-ton giant off the ground.

First stage
The Saturn V's kerosene-fuelled first stage lifts it to an altitude of 68km in 165 seconds, before falling away.

Second stage
Using liquid hydrogen fuel, the second stage takes over for another six minutes, getting close to orbital velocity.

Third stage
The third stage – also hydrogen-fuelled – is fired twice: once to enter Earth orbit, and then to push onwards to the Moon.

Instrument unit
It may look small and insignificant, but this is the brain of the Saturn V – its guidance computer.

Lunar Module shroud
On ascent, the LM is stowed inside this protective cover, attached to the Saturn V's instrument unit.

The ascent stage of the Lunar Module returning from the Moon's surface

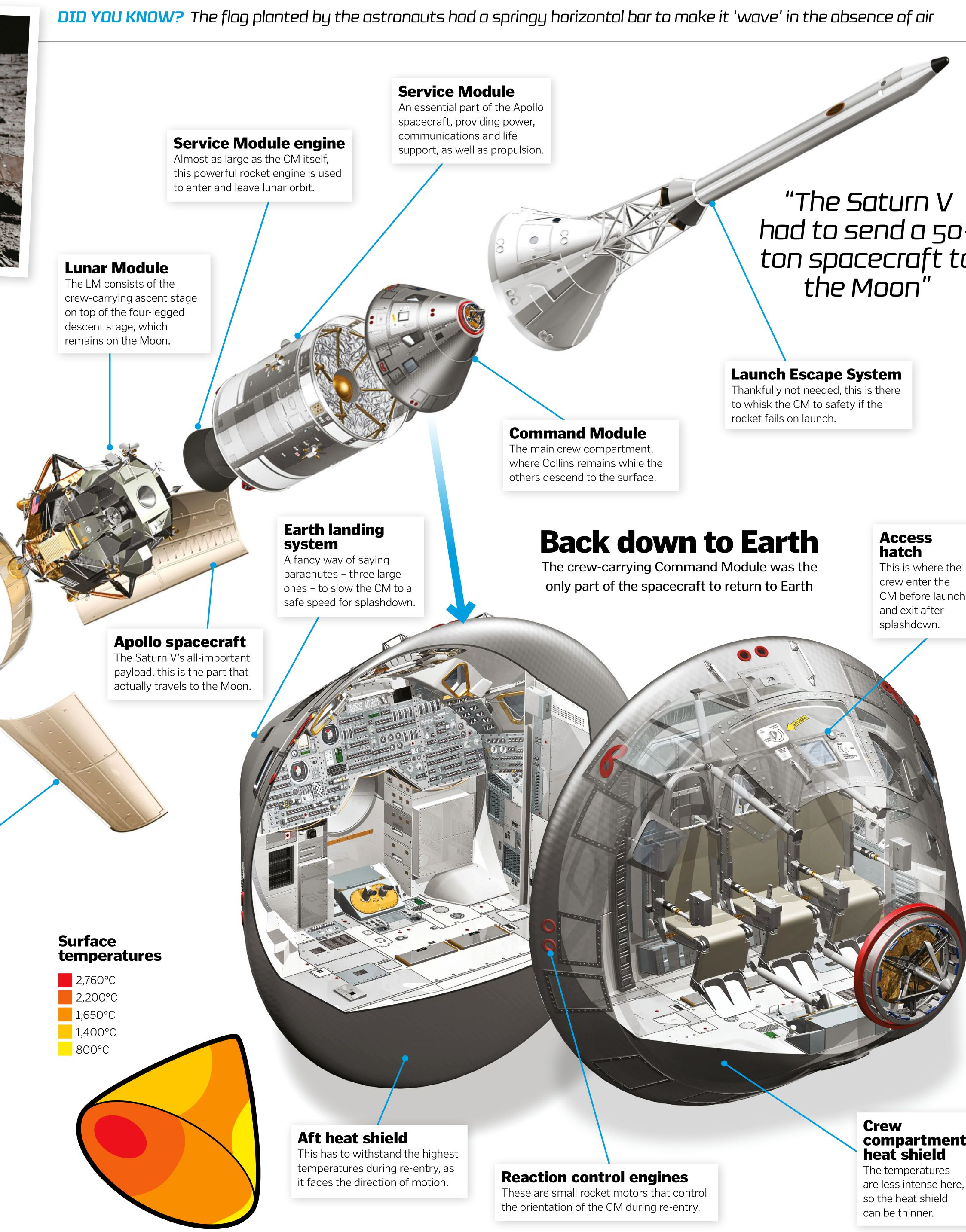
The 'impossible' lunar liftoff

At first sight, it seems odd that the Lunar Module's ascent stage, with just a single small rocket engine, was able to launch two astronauts off the Moon's surface. Didn't it require the enormous Saturn V to get three of them off the Earth? If you look into the physics, though, there isn't really any contradiction. The Saturn V had to send a 50-ton spacecraft all the way to the Moon, which calls for a speed of around 11 kilometres per second. In contrast, the LM ascent stage only had to lift itself – less than five tons – while the Moon's weaker gravity meant it could get into lunar orbit with a speed of just 1.6 kilometres per second. So a lot less energy was needed, which is why a smaller rocket did the job.

DID YOU KNOW? *The flag planted by the astronauts had a springy horizontal bar to make it 'wave' in the absence of air*

Back down to Earth

The crew-carrying Command Module was the only part of the spacecraft to return to Earth



"The Saturn V had to send a 50-ton spacecraft to the Moon"

Service Module
An essential part of the Apollo spacecraft, providing power, communications and life support, as well as propulsion.

Service Module engine
Almost as large as the CM itself, this powerful rocket engine is used to enter and leave lunar orbit.

Lunar Module
The LM consists of the crew-carrying ascent stage on top of the four-legged descent stage, which remains on the Moon.

Launch Escape System
Thankfully not needed, this is there to whisk the CM to safety if the rocket fails on launch.

Command Module
The main crew compartment, where Collins remains while the others descend to the surface.

Earth landing system
A fancy way of saying parachutes – three large ones – to slow the CM to a safe speed for splashdown.

Apollo spacecraft
The Saturn V's all-important payload, this is the part that actually travels to the Moon.

Access hatch
This is where the crew enter the CM before launch and exit after splashdown.

Surface temperatures

- 🟥 2,760°C
- 🟧 2,200°C
- 🟧 1,650°C
- 🟨 1,400°C
- 🟨 800°C

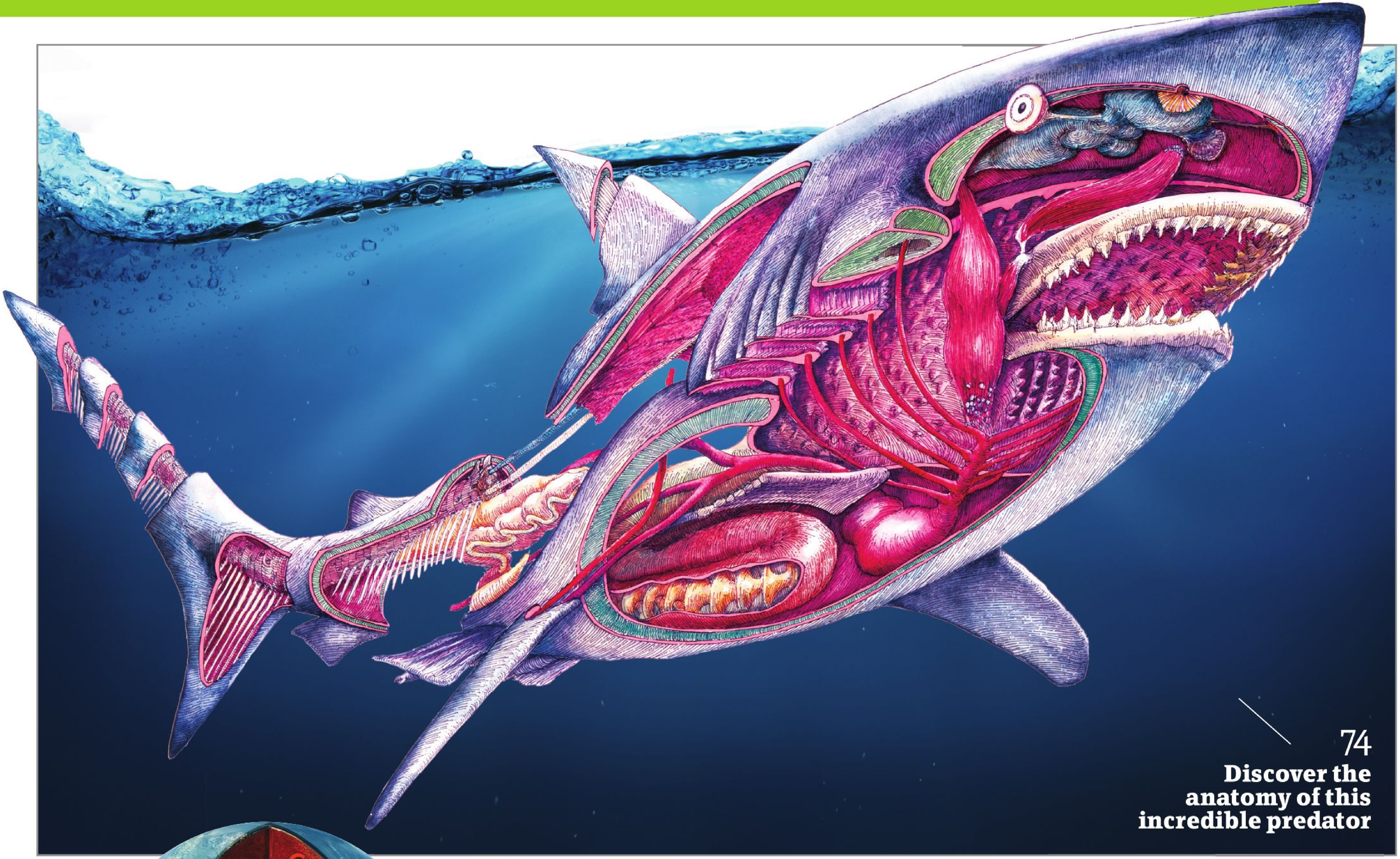
Aft heat shield
This has to withstand the highest temperatures during re-entry, as it faces the direction of motion.

Reaction control engines
These are small rocket motors that control the orientation of the CM during re-entry.

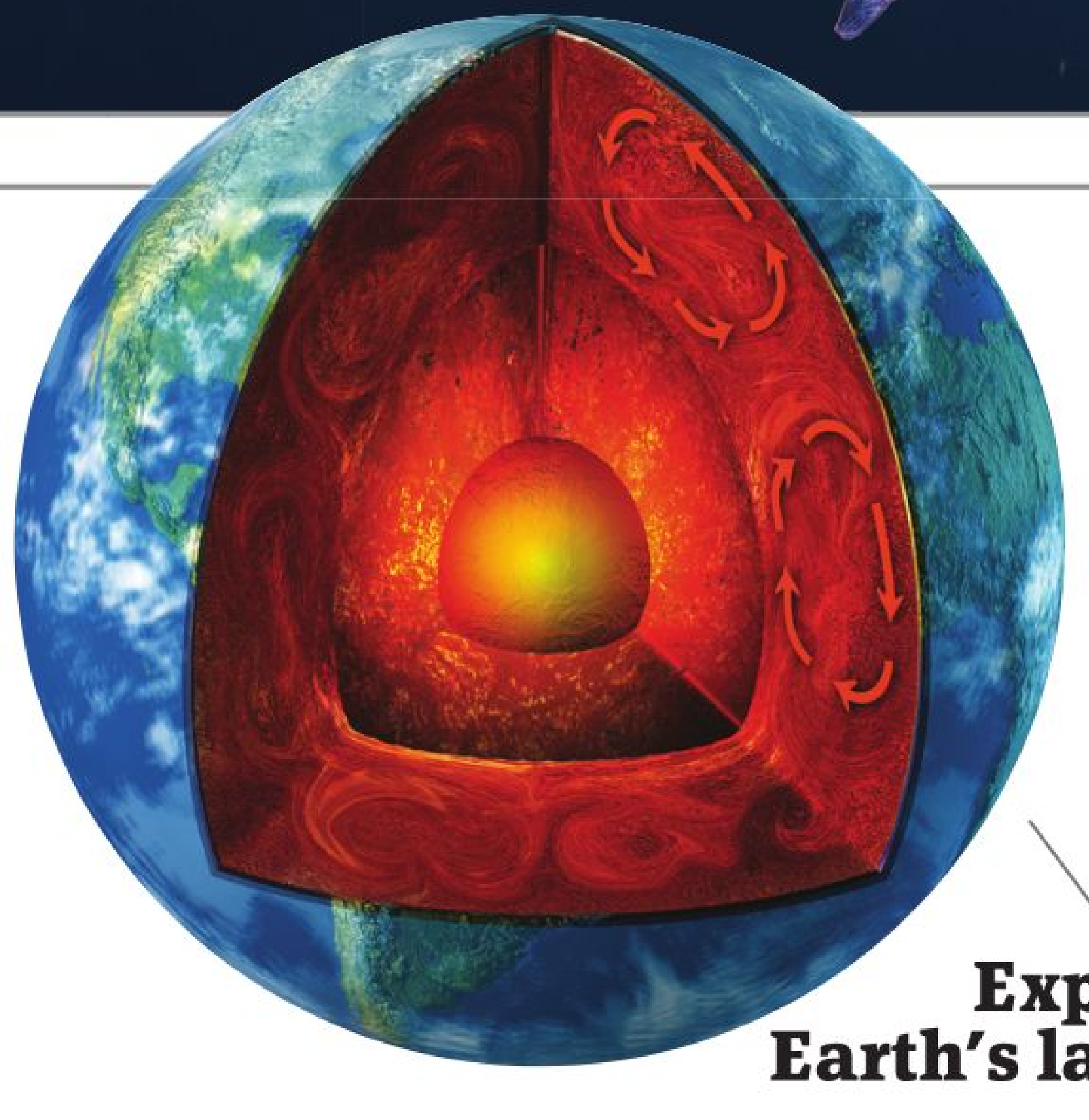
Crew compartment heat shield
The temperatures are less intense here, so the heat shield can be thinner.

© Science Photo Library

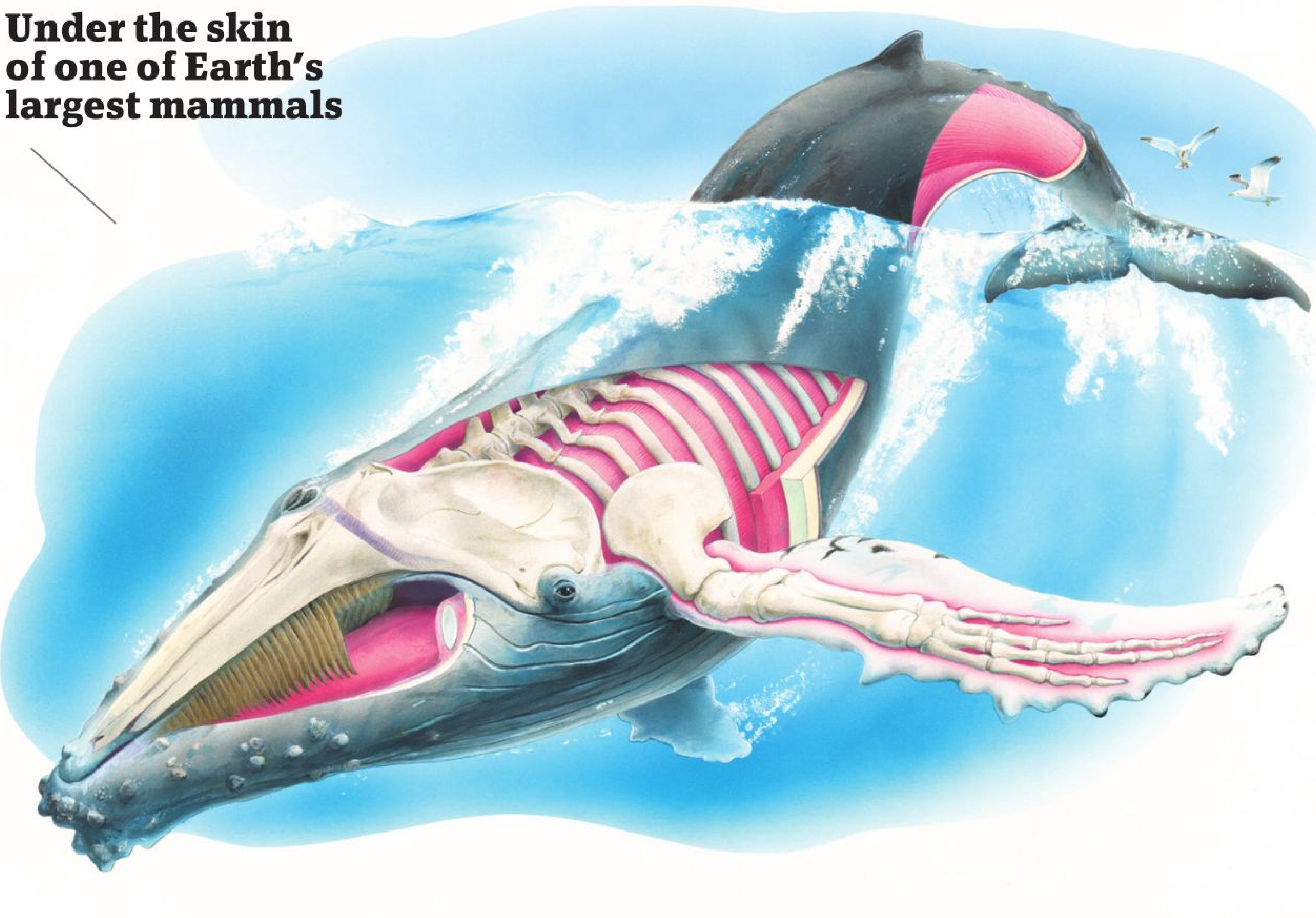
ENVIRONMENT



74
Discover the anatomy of this incredible predator

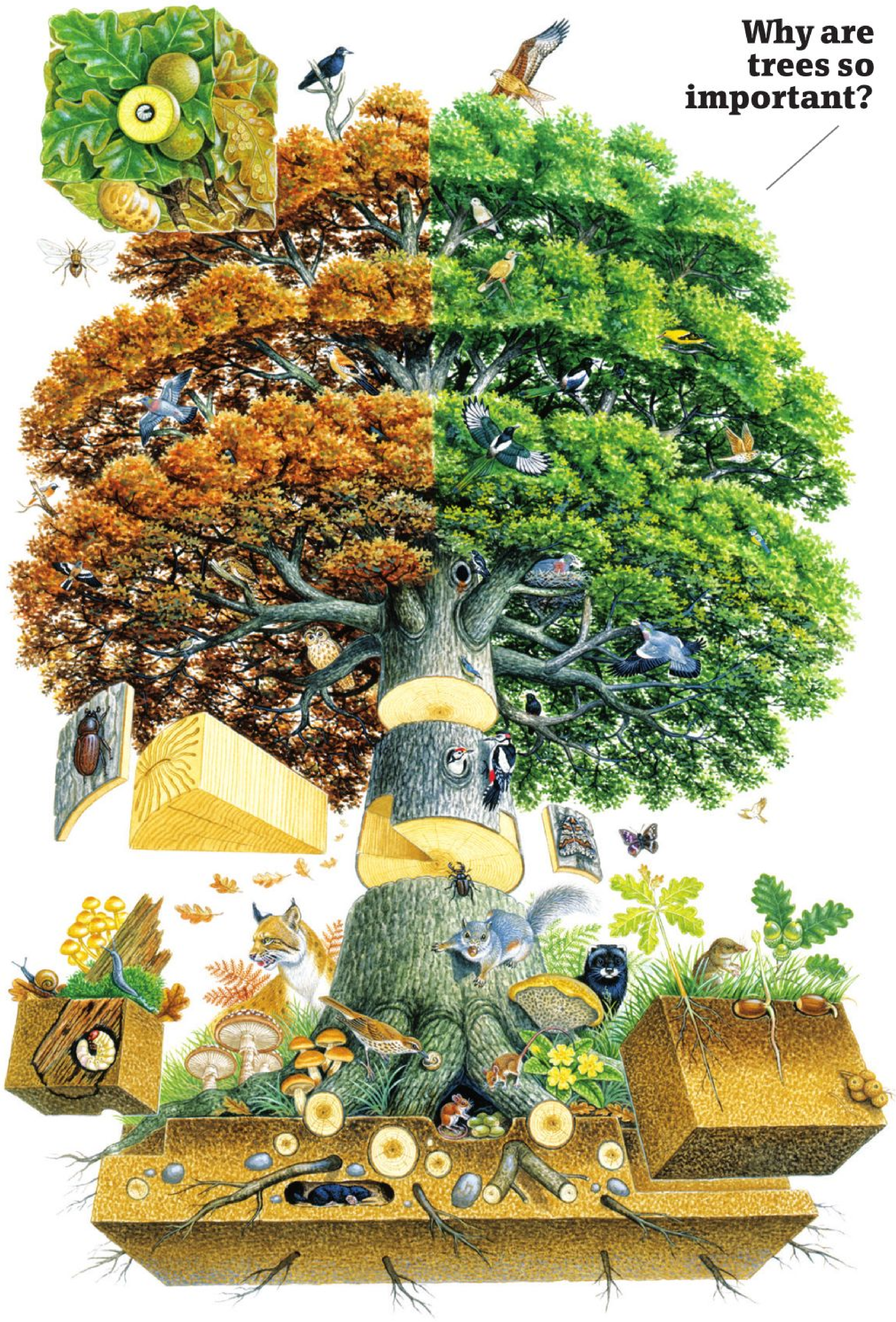


56
Explore Earth's layers



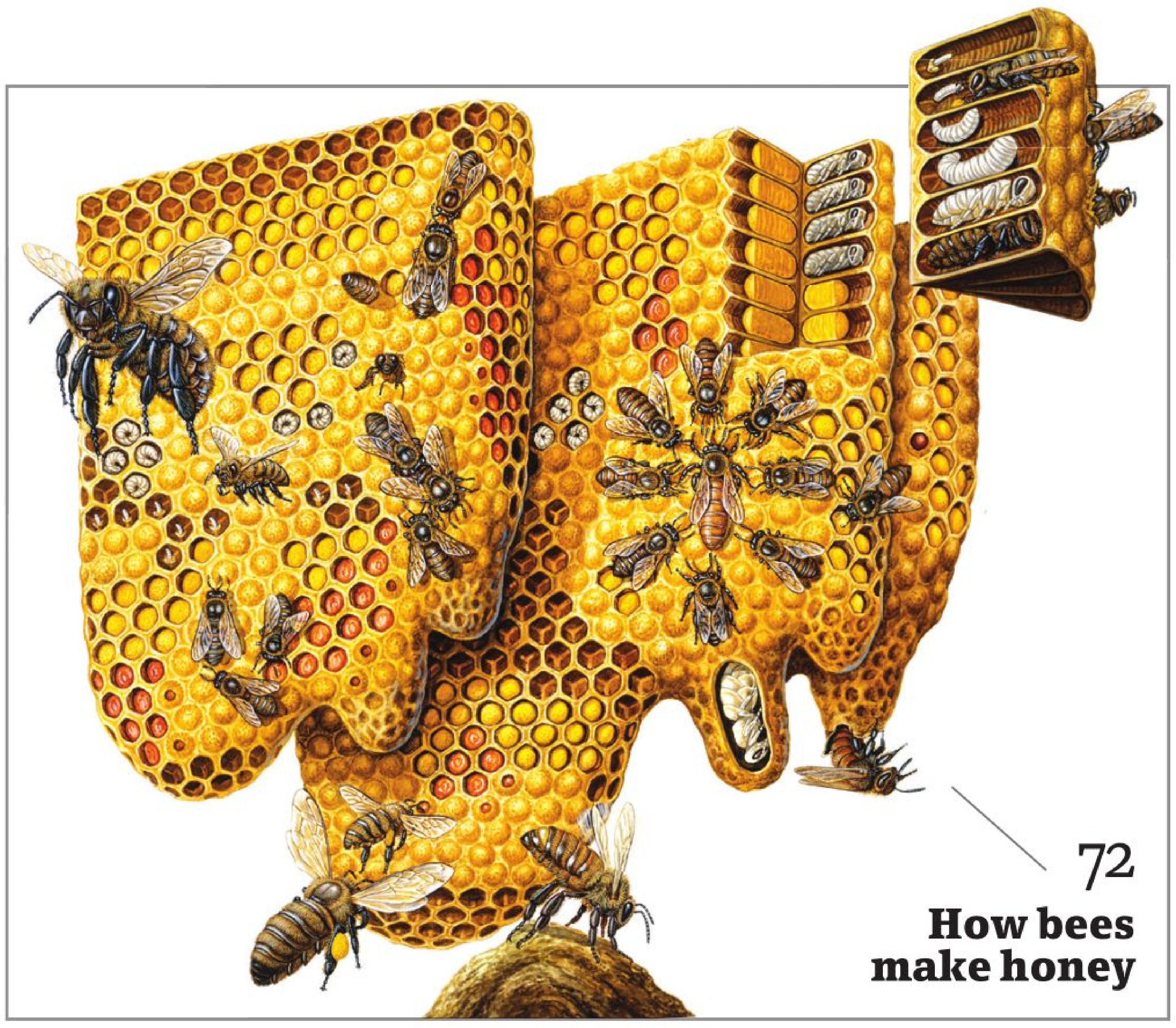
68
Under the skin of one of Earth's largest mammals

56 The Earth's structure
58 How tigers hunt
60 Trees of life
64 Anatomy of a volcano
66 What causes a landslide?
68 Humpback whales
70 How wells work
72 The honey factory
74 Shark anatomy



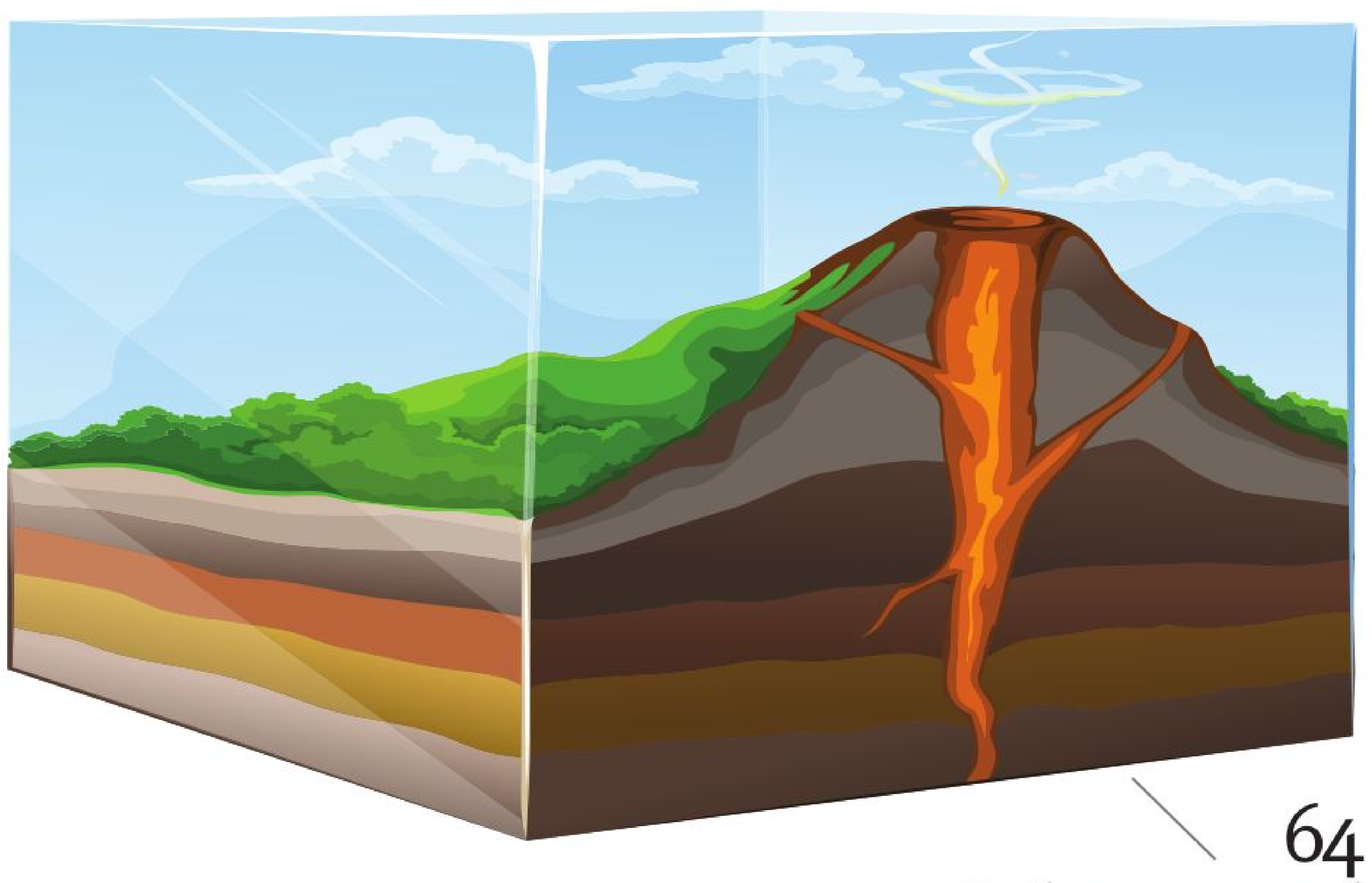
60

Why are trees so important?



72

How bees make honey

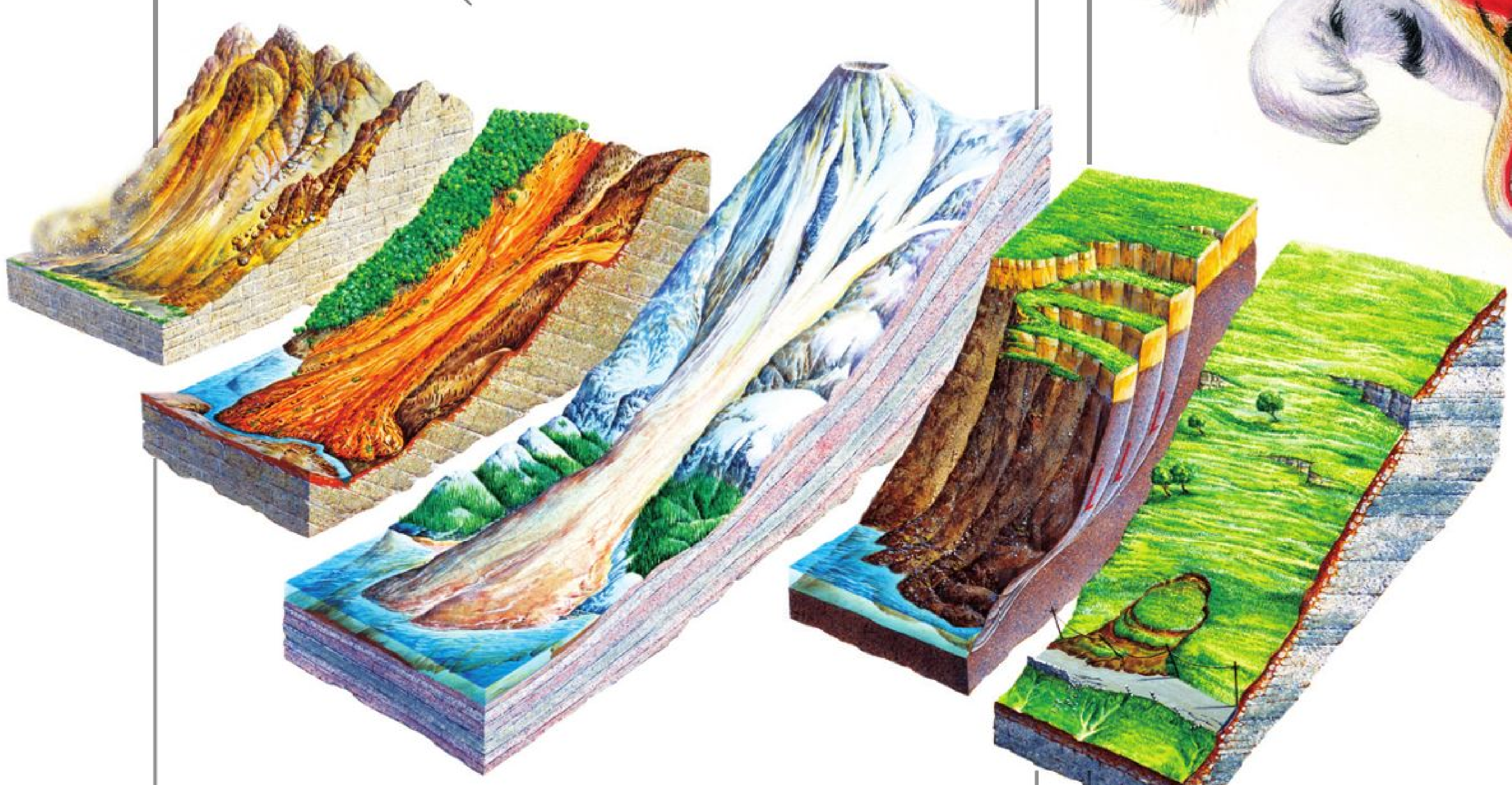


64

Volcanoes and how they work

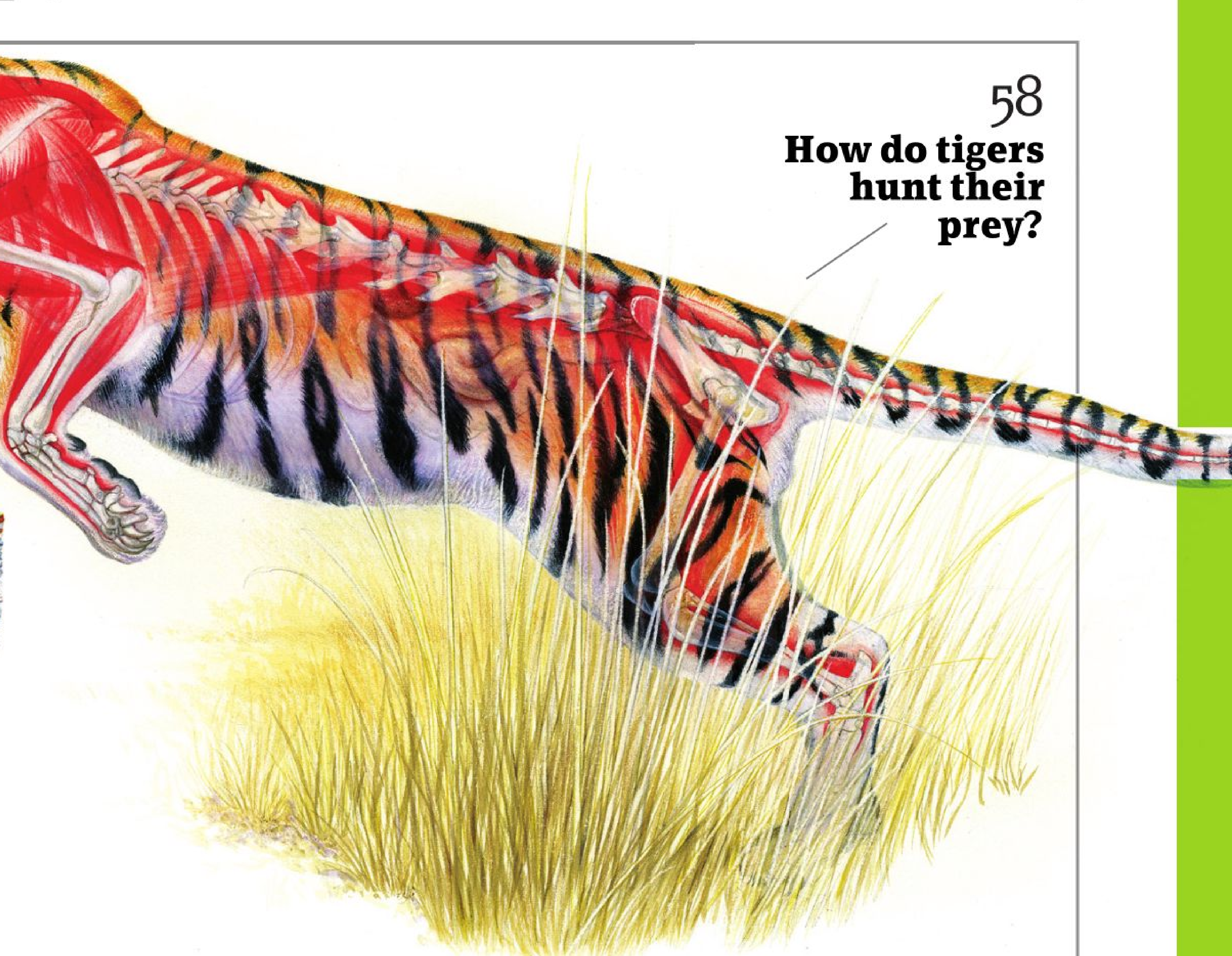
66

What causes landslides?



58

How do tigers hunt their prey?



The Earth's structure

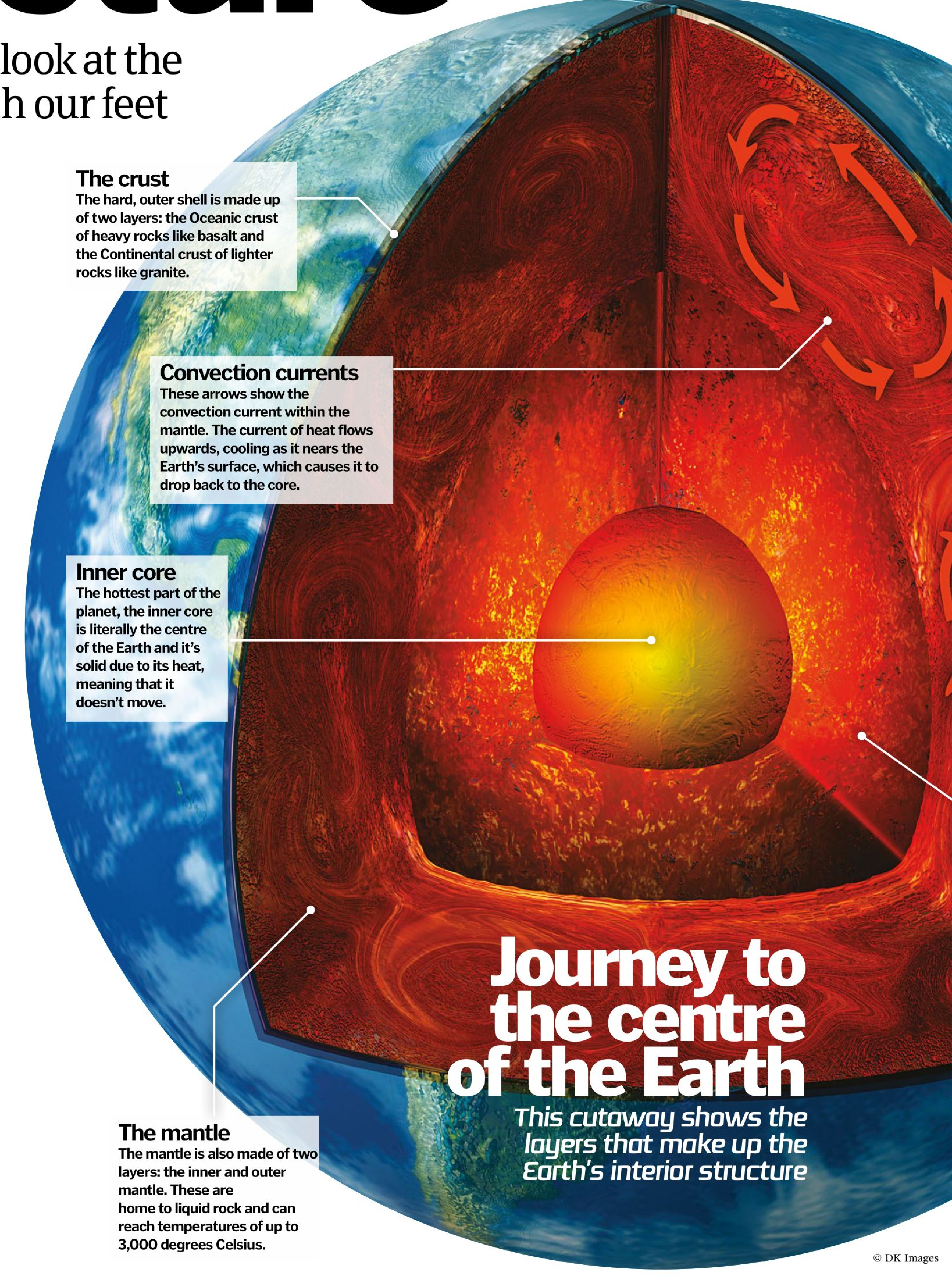
We take an in-depth look at the hidden world beneath our feet

We take the world around us for granted, but the Earth that we walk upon is a complex blend of layers that together create our planet. Thanks to research in the field of seismology, we now know the makeup of the Earth, its distances and measurements and can even compare it to other planets in our solar system.

Essentially, the internal structure of the Earth is made up of three core elements: the crust, the mantle and the core. The crust is the hard outer shell that we live on, split into Oceanic and Continental crusts, and it is comparatively thin. The first layer, the Oceanic crust, is around four to seven miles thick, made up of heavy rocks, whereas the lighter Continental crust is thicker, at approximately 19 miles.

Below the crust is the mantle, and again this is divided into two distinct layers: the inner and outer mantle. The outer mantle is the thinner of the two layers, occurring between seven miles and 190 miles below the Earth's surface. The outer mantle is made up of a bottom layer of tough liquid rock, with a temperature of somewhere between 1,400 degrees Celsius and 3,000 degrees Celsius, and a thinner, cooler upper layer. The inner mantle is deep into the Earth's structure, at between 190 and 1,800 miles deep, with an average temperature of 3,000 degrees Celsius.

Finally, we reach the Earth's core, which is 1,800 to 3,200 miles beneath our feet. The outer core is around 1,370 miles thick, encasing the inner core, which falls down to 3,960 miles below the Earth's surface. The inner core reaches a temperature high of 6,000 degrees Celsius and is made up of iron, nickel and other elements. While the outer core is liquid, the inner core is solid, and the two work together to cause the Earth's magnetism.



The crust
The hard, outer shell is made up of two layers: the Oceanic crust of heavy rocks like basalt and the Continental crust of lighter rocks like granite.

Convection currents
These arrows show the convection current within the mantle. The current of heat flows upwards, cooling as it nears the Earth's surface, which causes it to drop back to the core.

Inner core
The hottest part of the planet, the inner core is literally the centre of the Earth and it's solid due to its heat, meaning that it doesn't move.

The mantle
The mantle is also made of two layers: the inner and outer mantle. These are home to liquid rock and can reach temperatures of up to 3,000 degrees Celsius.

Journey to the centre of the Earth

This cutaway shows the layers that make up the Earth's interior structure

© DK Images

5 TOP FACTS EARTH'S AXIS

Day and night

1 During Earth's year-long orbit round the Sun, it also rotates once a day round its axis, an imaginary line passing through the North and South Poles, creating day and night.

The seasons

2 Earth's axis tilts at 23.5°. When Earth orbits the Sun, the North Pole spends six months leaning towards the Sun and six months leaning away from it.

The tides

3 The Earth's tides are caused by the gravity of the Moon. The Earth's water on the side nearest to the Moon is pulled causing the water to bulge, this is known as a high tide.

Spring tide

4 The Sun also affects the tides, and when the Sun and Moon are aligned with the Earth, their combined gravities create the highest tide, called spring tide.

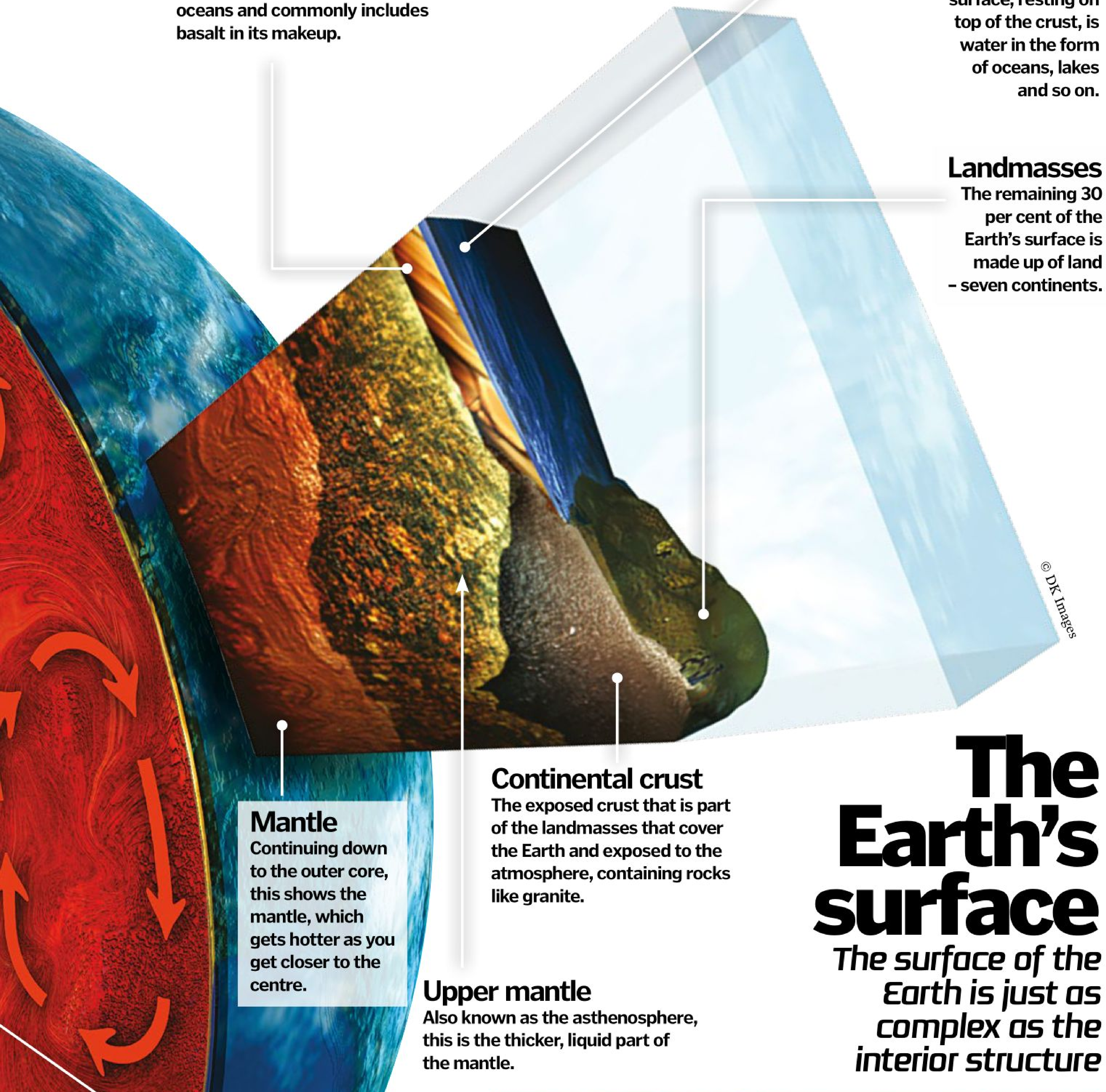
Neap tide

5 When the Sun and Moon are not lined up but are instead at right angles to each other, their gravities cancel each other out, creating the Earth's lowest neap tides.

DID YOU KNOW? *70 per cent of the Earth's surface is covered in water*

The Earth's surface

The surface of the Earth is just as complex as the interior structure



Oceanic crust
As suggested by its name, this lies underneath the Earth's oceans and commonly includes basalt in its makeup.

Water
Covering 70 per cent of the Earth's surface, resting on top of the crust, is water in the form of oceans, lakes and so on.

Landmasses
The remaining 30 per cent of the Earth's surface is made up of land – seven continents.

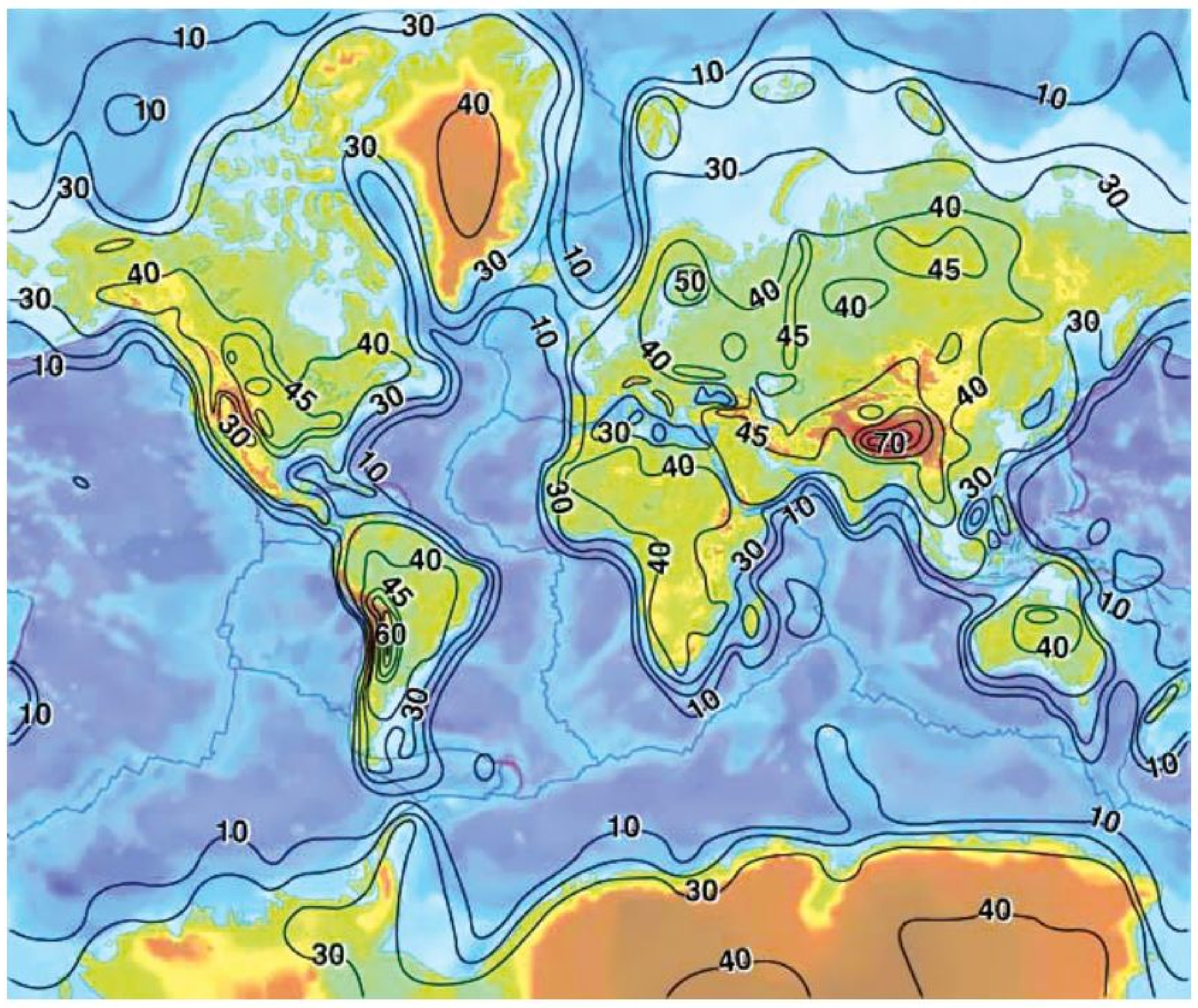
© DK Images

Mantle
Continuing down to the outer core, this shows the mantle, which gets hotter as you get closer to the centre.

Continental crust
The exposed crust that is part of the landmasses that cover the Earth and exposed to the atmosphere, containing rocks like granite.

Upper mantle
Also known as the asthenosphere, this is the thicker, liquid part of the mantle.

Outer core
The liquid, outer core is made up of iron, nickel, sulphur and oxygen. This outer core spins as the Earth rotates.



Crust thickness

A contour map of the globe, showing the thickness of the Earth's crust, with the numbers in kilometres.

How the Earth formed

A complicated procedure brought together the many elements of the Earth and even today the planet is adapting and changing

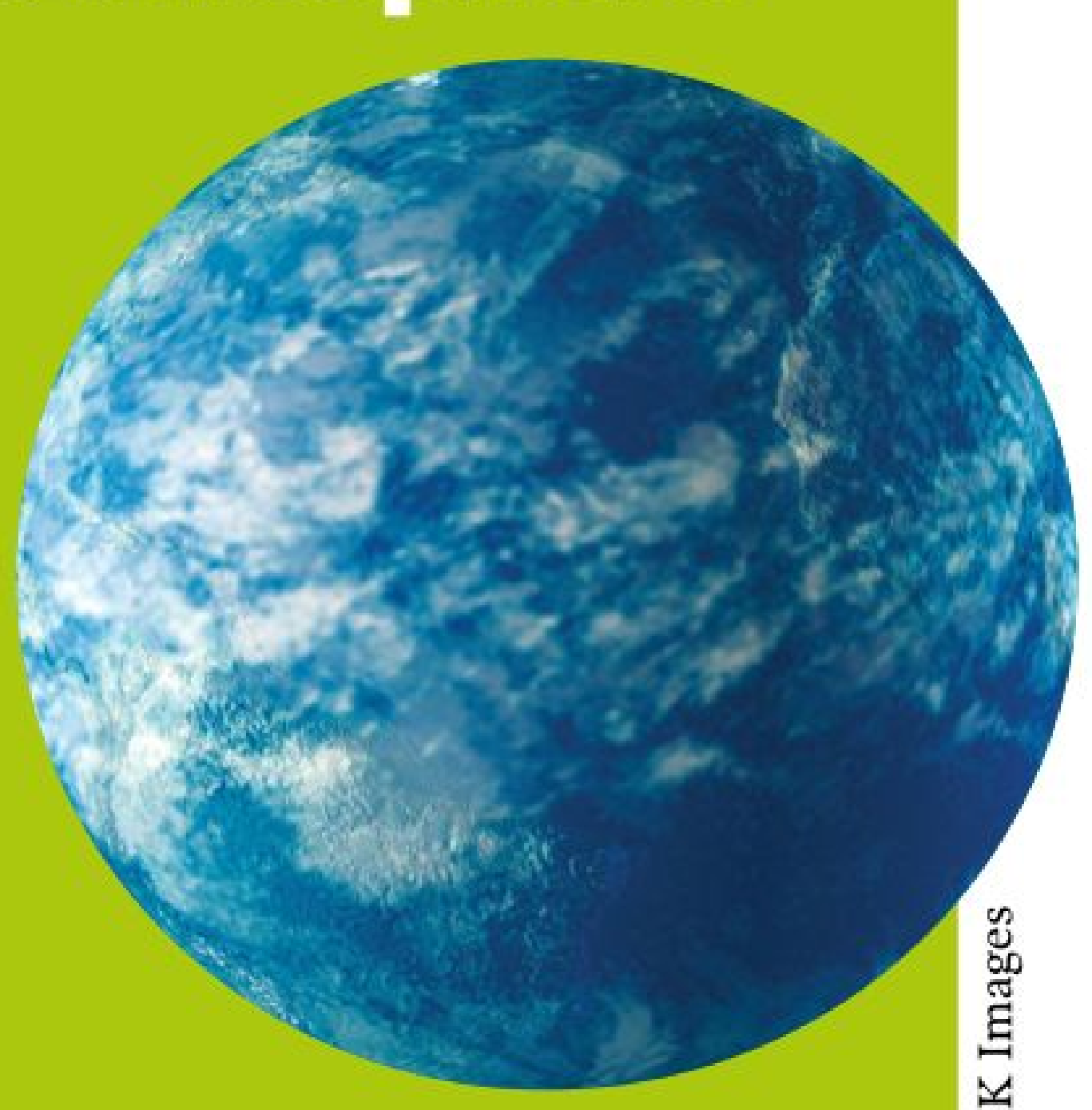
Accretion

Accretion describes the gradual increase in size of an object through the accumulation of additional layers. In the case of Earth, this is how rocks and metals built upon each other to form the core.

Heating and cooling

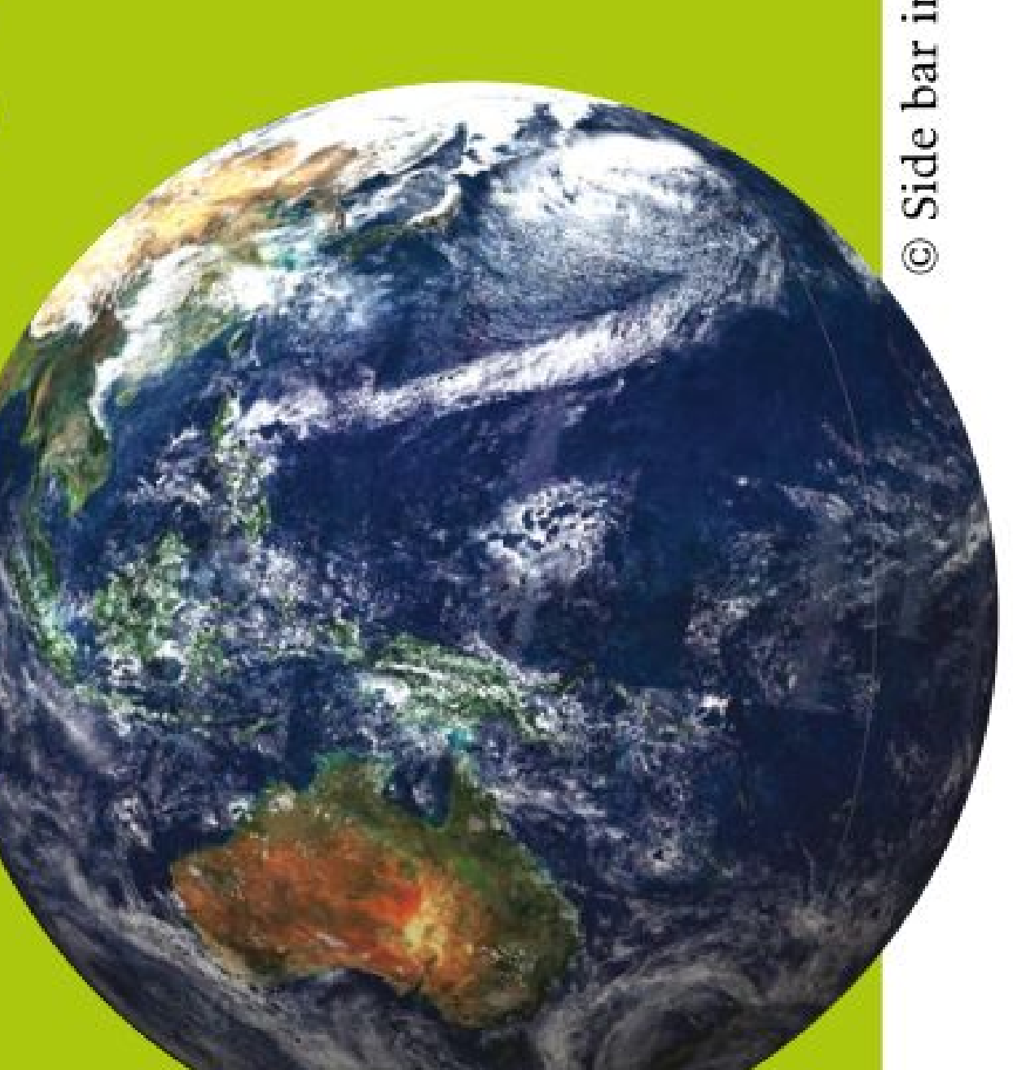
The process of creating planets via accretion causes friction and collisions that create a heat, which partly explains the temperature at the Earth's core. As this cooled in the planet's formation, the crust hardened.

Oceans and atmosphere



Steam from the crust combined with gases from volcanoes to create the atmosphere and water. As the planet cooled, clouds formed, causing rain, which in turn caused the oceans.

Today's Earth



Though we rarely see the results, the Earth's surface continues to change as landmasses collide and break apart, thanks to the dynamic properties of the Earth's interior structure, which can move land by centimetres each year.

© Side bar images: DK Images

How tigers hunt

These killer cats take down their prey solo, without any help from a pack

Poised between the blades of the tall grass in the savanna, a feline body is crouched like a coiled spring, ready to pounce on a passing deer. Within seconds this striped assassin leaps from its grassy hideout, delivering a fatal blow to the back of the deer's neck before feasting on its victim's flesh.

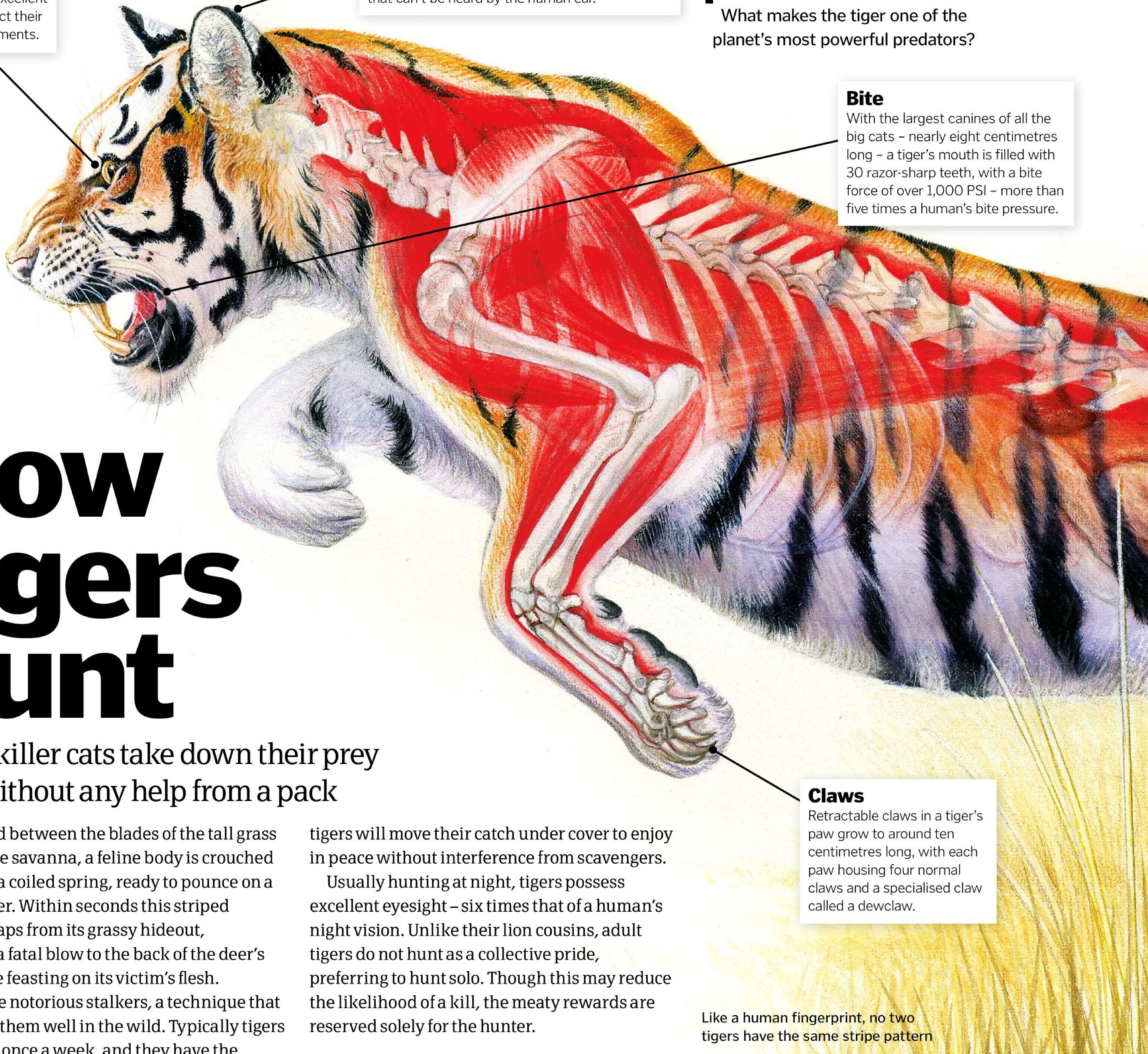
Tigers are notorious stalkers, a technique that has served them well in the wild. Typically tigers make a kill once a week, and they have the ability to consume up to 40 kilograms of food in a single sitting. With a diet almost exclusively made up of meat, they have fine-tuned hunting skills, placing them at the top of the food chain as an apex predator.

Tigers will tentatively stalk their future meal until they're within six to nine metres away. Once in range, tigers target their prey's neck, which severs its spinal cord. Larger meals may also require a fatal bite to the throat to drag them to the ground. As capable swimmers, tigers also utilise surrounding water to drag down and drown resistant prey. Once the struggle is over, tigers will move their catch under cover to enjoy in peace without interference from scavengers.

Usually hunting at night, tigers possess excellent eyesight – six times that of a human's night vision. Unlike their lion cousins, adult tigers do not hunt as a collective pride, preferring to hunt solo. Though this may reduce the likelihood of a kill, the meaty rewards are reserved solely for the hunter.

Anatomy of a peerless hunter

What makes the tiger one of the planet's most powerful predators?

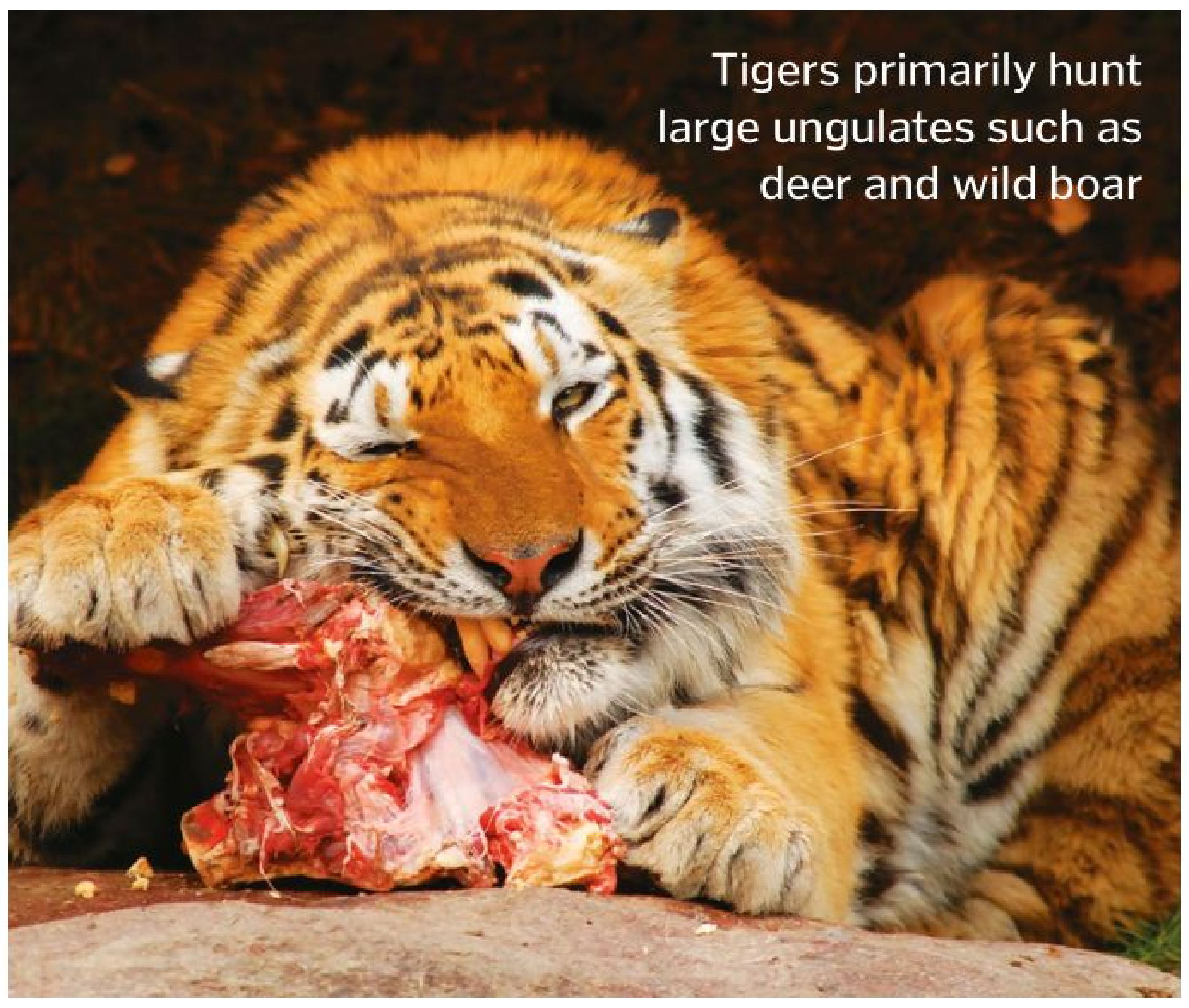


Sight
As typically nocturnal hunters, tigers have excellent sight to detect their prey's movements.

Hearing
A tiger has the ability to hear sounds up to 300-500Hz, along with low-frequency infrasound that can't be heard by the human ear.

Bite
With the largest canines of all the big cats – nearly eight centimetres long – a tiger's mouth is filled with 30 razor-sharp teeth, with a bite force of over 1,000 PSI – more than five times a human's bite pressure.

Claws
Retractable claws in a tiger's paw grow to around ten centimetres long, with each paw housing four normal claws and a specialised claw called a dewclaw.



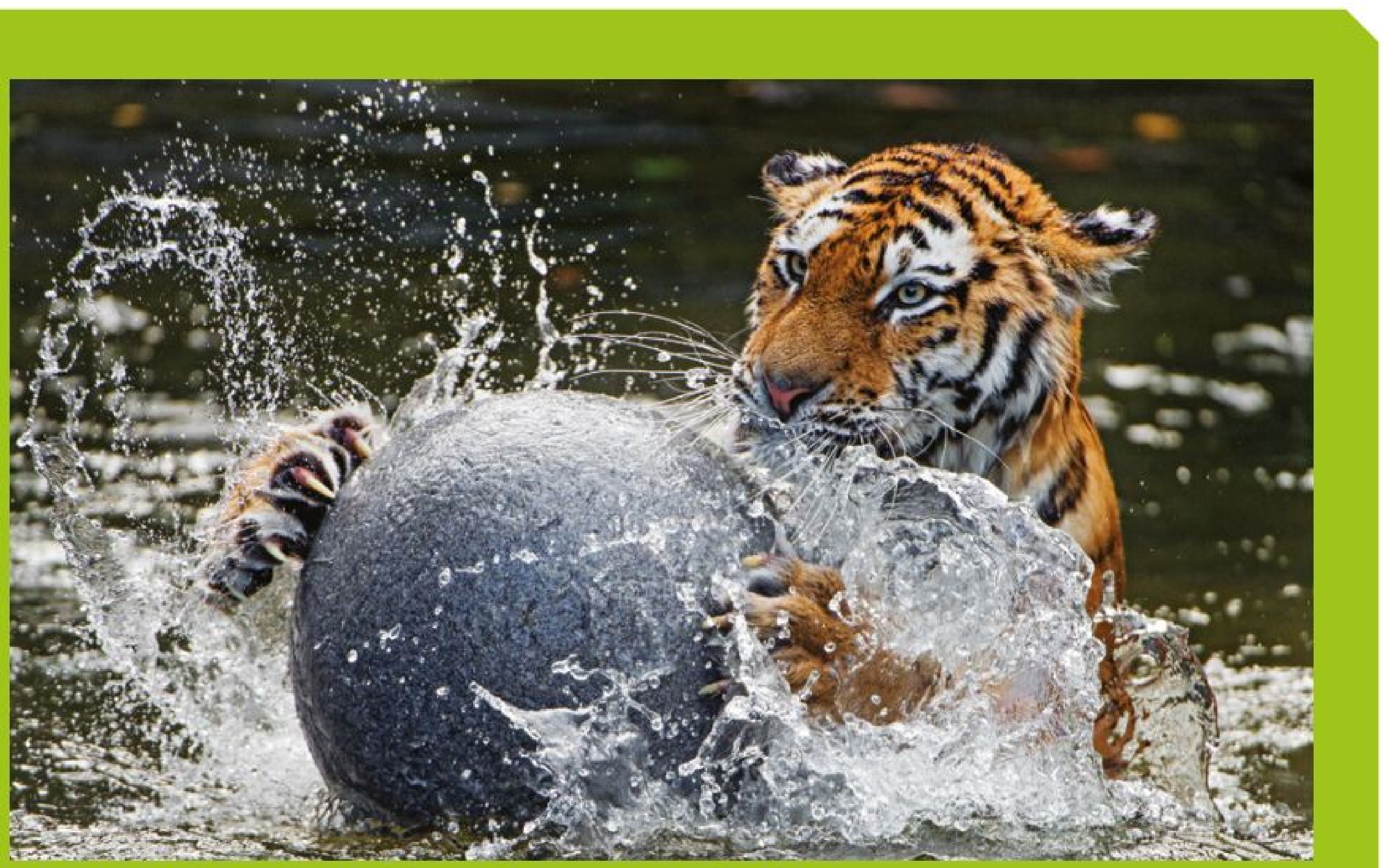
Tigers primarily hunt large ungulates such as deer and wild boar

Like a human fingerprint, no two tigers have the same stripe pattern

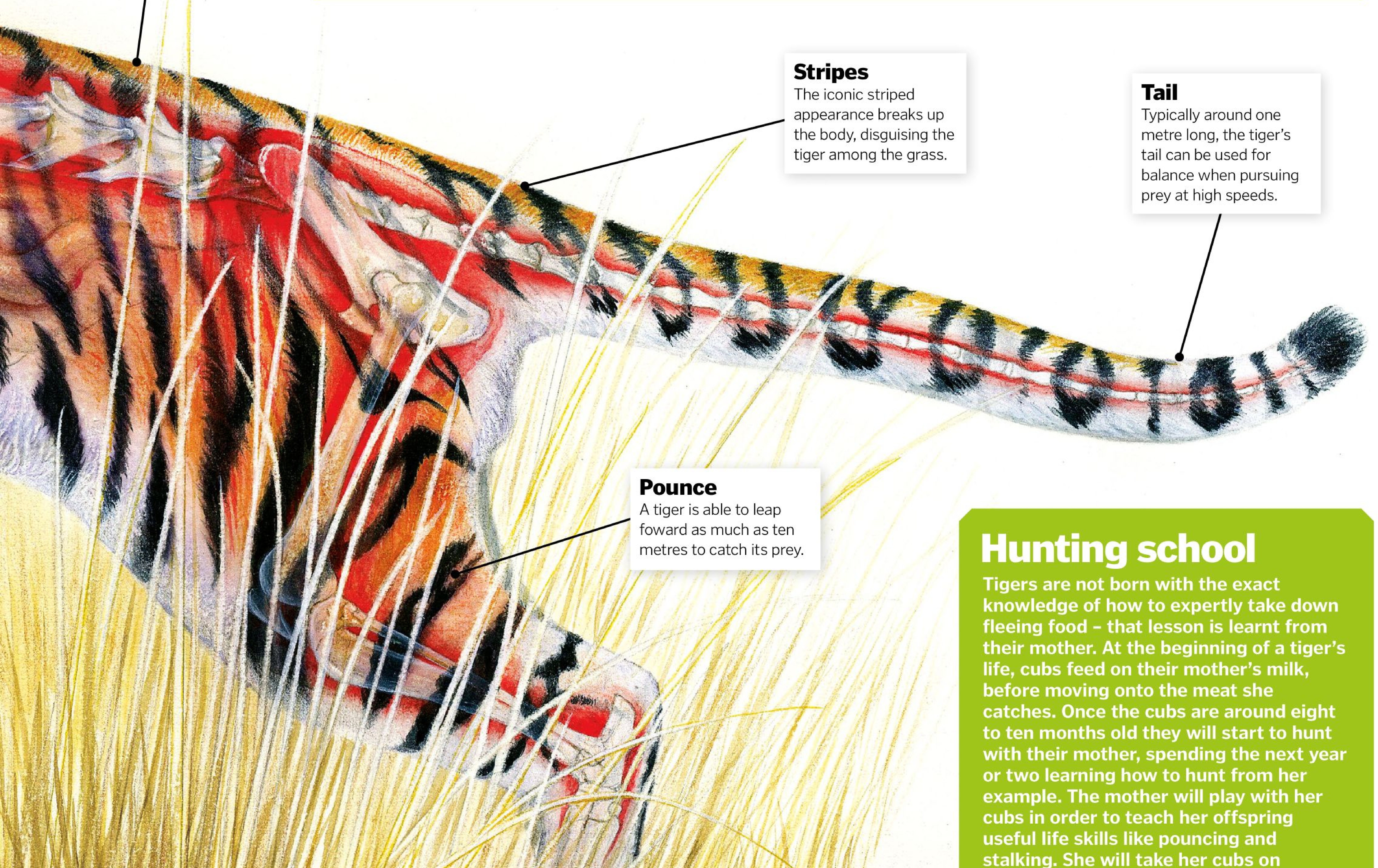
DID YOU KNOW? *The roar of a tiger can be heard up to three kilometres away*

Hunting in captivity

With more tigers living in captivity than in the wild (up to 7,000 in the US alone, compared to around 3,890 wild individuals worldwide), zookeepers have come up with different ways to satisfy tigers' desire to hunt. As introducing live prey into enclosures is strictly prohibited, zookeepers aim to mimic aspects of prey by artificial means. The Smithsonian's National Zoo in Washington, US, has a novel approach to allowing the resident tigers to display their predatory behaviour. Large, sturdy balls known as 'boomer balls' are used for tigers and other big cats to chase and interact with like live prey. Other methods of hunting enrichment include animating animal carcasses or creating prey species out of cardboard for tigers to stalk and hunt.



Tigers will stalk and hunt boomer balls that are tough enough to withstand their bites



Speed
To chase after its prey, a tiger can run in bursts of up to 65 kph.

Stripes
The iconic striped appearance breaks up the body, disguising the tiger among the grass.

Tail
Typically around one metre long, the tiger's tail can be used for balance when pursuing prey at high speeds.

Pounce
A tiger is able to leap foward as much as ten metres to catch its prey.

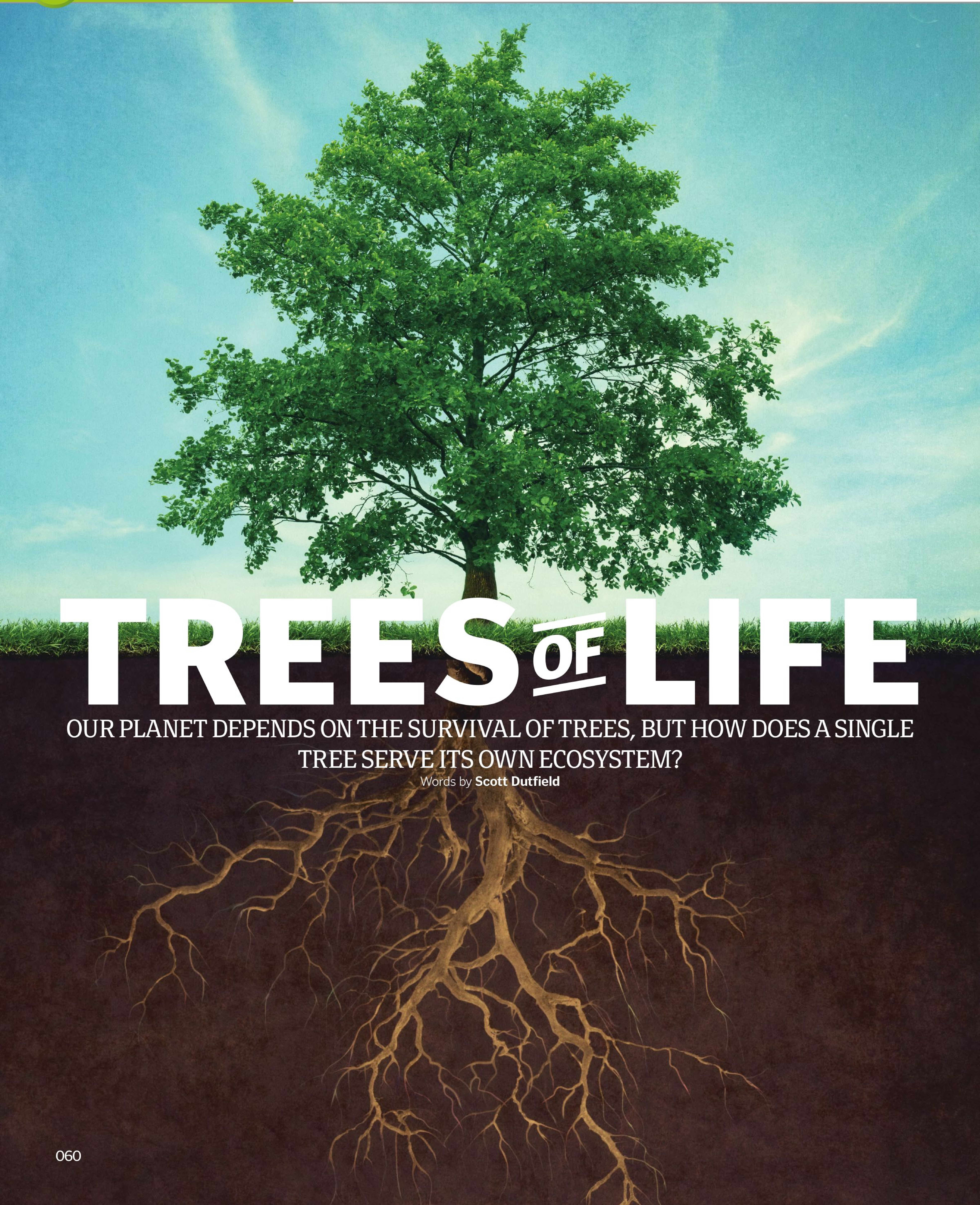
Hunting school

Tigers are not born with the exact knowledge of how to expertly take down fleeing food – that lesson is learnt from their mother. At the beginning of a tiger's life, cubs feed on their mother's milk, before moving onto the meat she catches. Once the cubs are around eight to ten months old they will start to hunt with their mother, spending the next year or two learning how to hunt from her example. The mother will play with her cubs in order to teach her offspring useful life skills like pouncing and stalking. She will take her cubs on hunting expeditions to showcase how a kill is made, in the hope that the cubs will mimic her technique. Once their training is complete, the next generation of hunters will leave their mother's side and seek their own territories in which to hunt for prey.

Estimates suggest that every tiger consumes 50 deer-sized animals each year

Tiger cubs stay with their mother for around two years, learning how to hunt as they grow

© Getty; Alamy



TREES OF LIFE

OUR PLANET DEPENDS ON THE SURVIVAL OF TREES, BUT HOW DOES A SINGLE TREE SERVE ITS OWN ECOSYSTEM?

Words by **Scott Dutfield**

DID YOU KNOW? *The average human exhales over one kilogram of carbon dioxide per day*

Reaching across millions of kilometres, the world's forests are the heart and soul of our global ecosystem. Trees are the yin to mankind's yang: they absorb the carbon dioxide we exhale, and in return they release the precious oxygen our bodies depend on, creating an atmospheric balance. During a tree's lifetime, it will absorb a ton of carbon dioxide, producing around 118 kilograms of oxygen a year in return.

While collectively acting as Earth's air purifier, each individual tree exists in its own micro-ecosystem. From seedling to skyscraper, trees are often at the centre of these ecosystems, facing the demands for food, shelter and protection from other species. For example, a single tree growing in a tropical rainforest can support around 2,000 different species from across the animal kingdom as well as plant and fungi species.

Fundamentally the role of trees in a micro-ecosystem is to transfer energy in a biological chain, from sunlight to seed production and beyond. Through photosynthesis, trees utilise the energy of the Sun's light to transform absorbed carbon dioxide and water into glucose and oxygen. Stored as chemical energy in glucose, a tree will use this to grow its leafy body and produce its fruits. This chemical energy is then transferred once more to the animals and insects via a free buffet of fruits, leaves, pollen and nuts. In turn, these creatures will use this obtained energy to survive, and even benefit the tree by dispersing its seeds.

> "Each individual tree exists in its own micro-ecosystem"

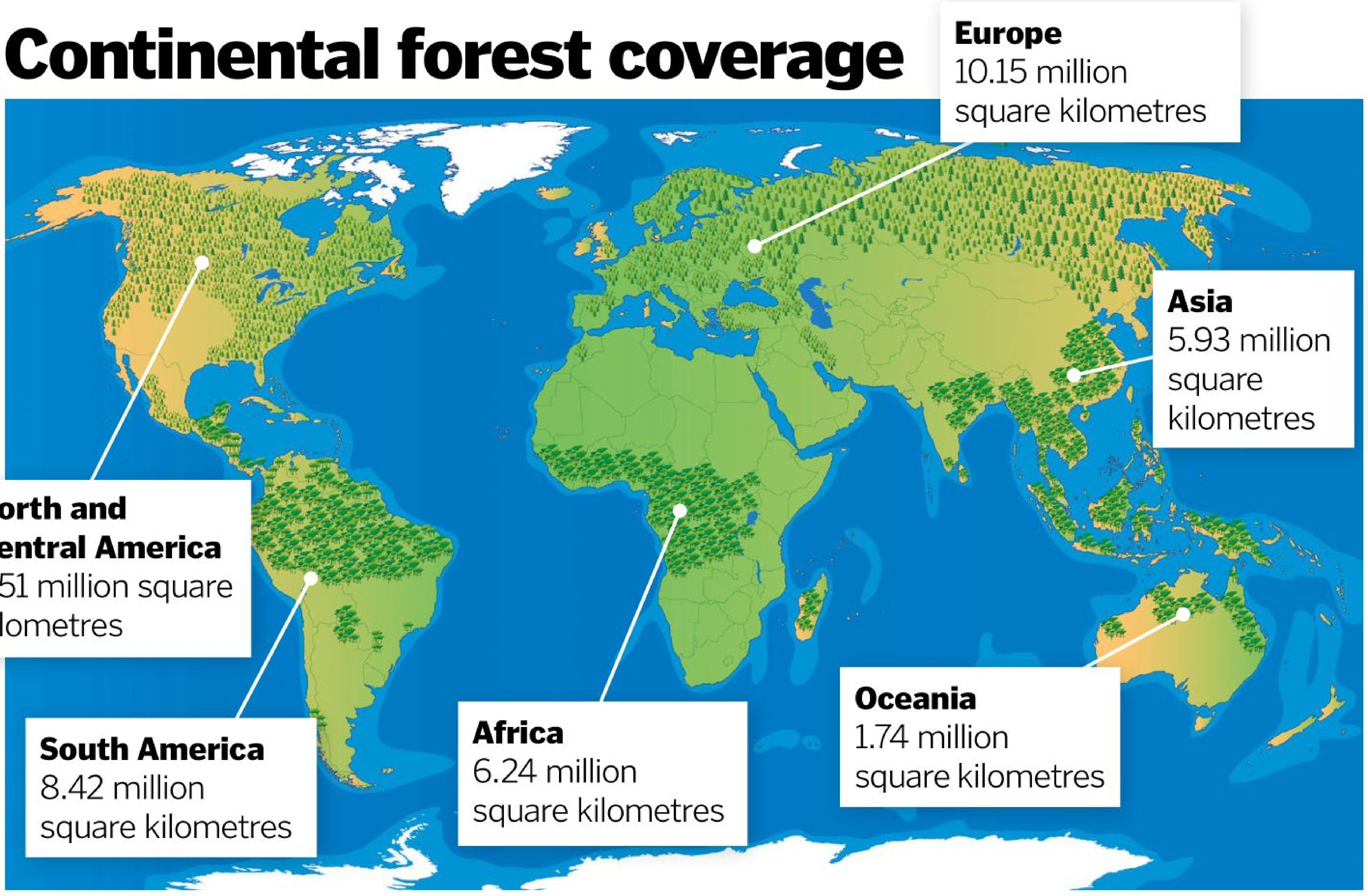
This gifting of energy is not the only way in which trees serve members of a biological community. Non-living 'abiotic' parts of an ecosystem are also kept in check by the presence of trees. Both a tree and the soil it is rooted in mutually benefit from the other's existence. Soil acts as a tree's resource bank of water, minerals and nutrients to be withdrawn by its roots, while fallen leaves and branches restore nutrients to the ground as they decompose. The complex network of roots not only anchor the tree but compact the soil to save it from erosion by rainfall.

The biological and chemical interactions surrounding a single tree are intertwined and affected by the rest of the forest ecosystem and our global ecosystem. A disturbance to smaller ecosystems can have a domino effect on larger ones. For example, during the process of deforestation, each biological community supported by a single tree is also removed. In turn, this can have a negative effect on the diversity of species and the fertility of the land.

© Getty

Gumivores such as the pygmy marmoset feast on the oozing sap of a tree

Continental forest coverage


Europe
10.15 million square kilometres
Asia
5.93 million square kilometres
North and Central America
7.51 million square kilometres
South America
8.42 million square kilometres
Africa
6.24 million square kilometres
Oceania
1.74 million square kilometres

© Getty

Gall wasp larvae release a chemical to create their own homes on a tree

© Alamy

The acorn and the wasp

Creating a habitat for animals and insects is a significant role of an oak tree, even when it's tricked into doing so. Found across the leaves, bark and even acorns of many oak trees are small plant pimples called galls. Although they appear as part of the tree's natural knobbly development, galls are in fact the result of a particular group of wasps forcing the tree to build them their very own safe haven. Upon laying its eggs in the tree, the gall wasp larvae secrete saliva that affects the tree's growth process. In response, the oak tree produces these strange growths, which encase the larvae within. Once engulfed in their temporary wooden shield, the wasp larvae pupate and later emerge as adult wasps.

© Getty

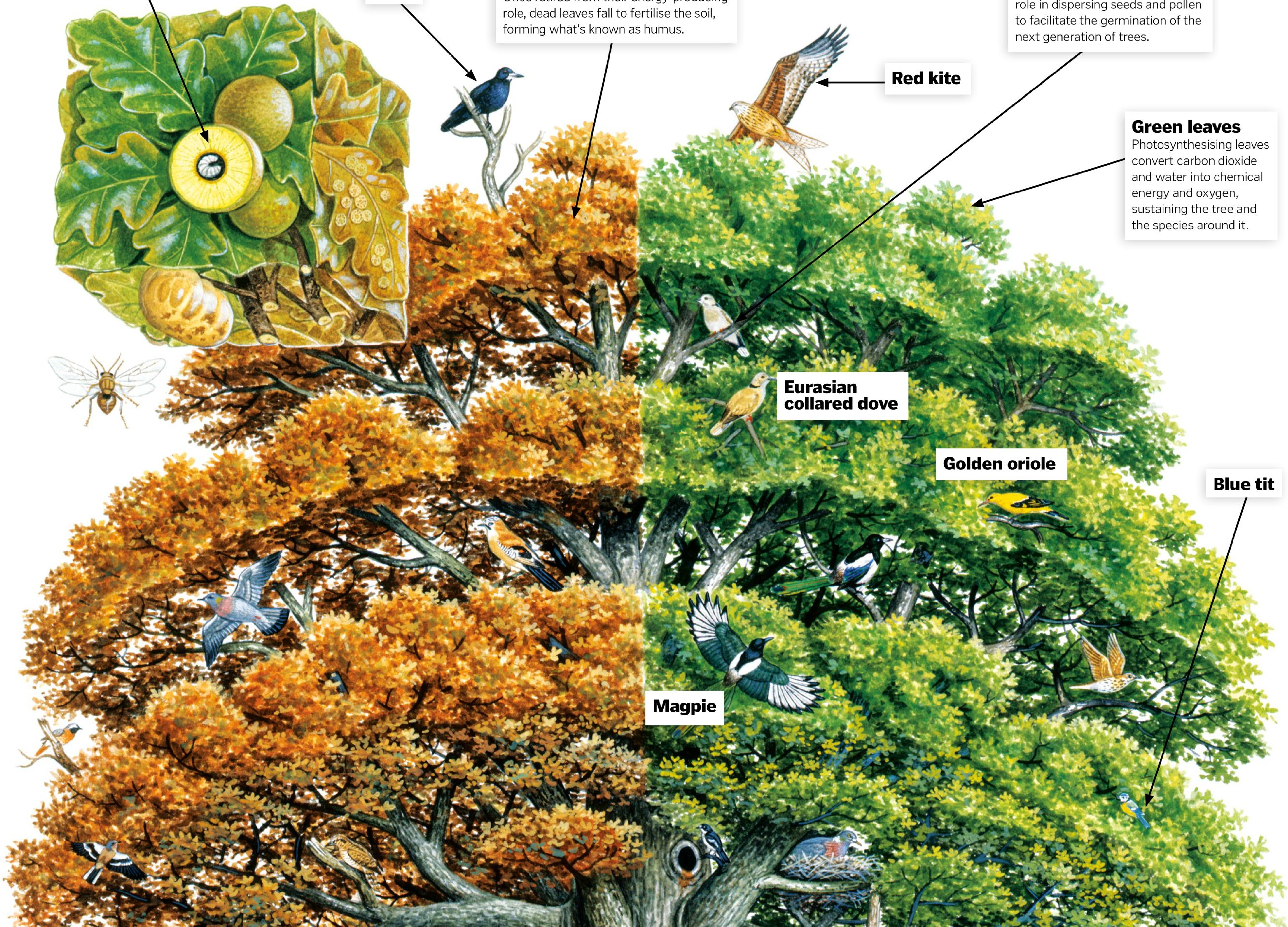
Many mammal species, such as the pine marten, make use of tree hollows to form their own home

© Getty

Lichen can act as a biological indicator of the health of an ecosystem because it absorbs pollution

THE MIGHTY OAK

A single oak is brimming with biodiversity throughout the year



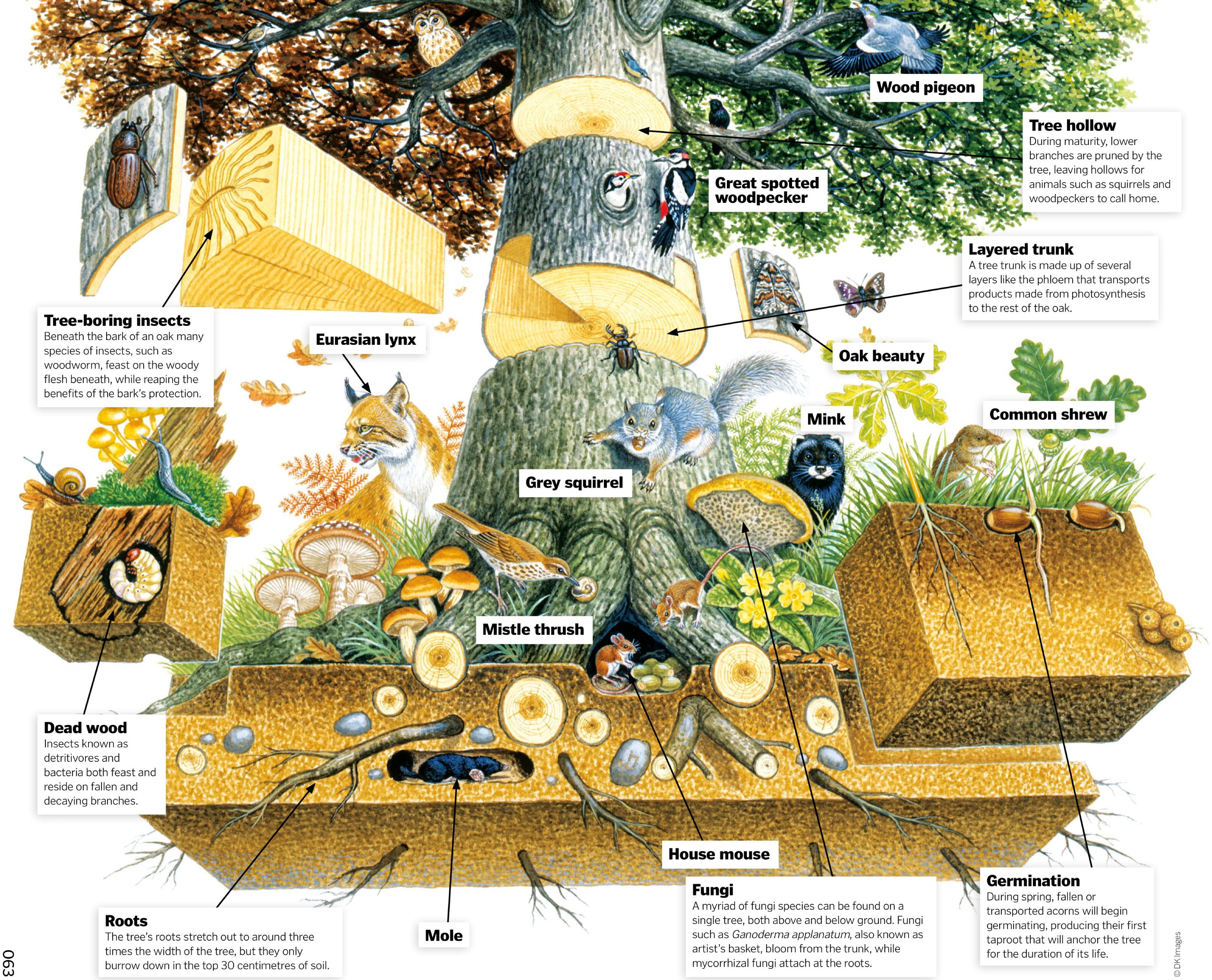
Seeds
Each acorn on an oak tree holds a single seed and will only be produced when a tree reaches the age of around 40 years old.

Autumn leaves
Once retired from their energy-producing role, dead leaves fall to fertilise the soil, forming what's known as humus.

Dispersal
Bird and insect species play a key role in dispersing seeds and pollen to facilitate the germination of the next generation of trees.

Green leaves
Photosynthesising leaves convert carbon dioxide and water into chemical energy and oxygen, sustaining the tree and the species around it.

DID YOU KNOW? *According to a recent survey, there are 60,065 different species of tree worldwide*



Tree hollow
During maturity, lower branches are pruned by the tree, leaving hollows for animals such as squirrels and woodpeckers to call home.

Layered trunk
A tree trunk is made up of several layers like the phloem that transports products made from photosynthesis to the rest of the oak.

Tree-boring insects
Beneath the bark of an oak many species of insects, such as woodworm, feast on the woody flesh beneath, while reaping the benefits of the bark's protection.

Dead wood
Insects known as detritivores and bacteria both feast and reside on fallen and decaying branches.

Roots
The tree's roots stretch out to around three times the width of the tree, but they only burrow down in the top 30 centimetres of soil.

Fungi
A myriad of fungi species can be found on a single tree, both above and below ground. Fungi such as *Ganoderma applanatum*, also known as artist's basket, bloom from the trunk, while mycorrhizal fungi attach at the roots.

Germination
During spring, fallen or transported acorns will begin germinating, producing their first taproot that will anchor the tree for the duration of its life.

© DK Images

Head to Head

Which is the biggest, fastest, strongest?

1. Mauna Loa

Location: Hawaii, USA

Height: At 17km (56,000ft) above its submarine base, Mauna Loa is not only the world's tallest volcano, but arguably the world's tallest mountain.

Last eruption: In 1984, after a series of earthquakes, rifts along Mauna Loa's flanks oozed slow-moving lava for three weeks, threatening the town of Hilo.

BIGGEST ERUPTION

2. Tambora

Location: Sumbawa, Indonesia

Height: 2,859 meters (9,348ft), but was 4,000 meters (13,000ft) prior to 1815

Last eruption: Tambora's 1815 eruption is the largest in recorded history, emitting 150 times more ash than Mt St Helens, killing 92,000 people and creating a worldwide 'year without a summer'.

3. Nevado del Ruiz

Location: Colombia

Height: 5,321 meters (17,453ft)

Last eruption: In 1985, a relatively small volcanic eruption melted a thick snow and ice cap, creating a killer lahar (mudslide) that descended on the village of Armero. A 30-metre high wall of water and debris killed over 20,000.

Beneath the Earth's crust

The instructions to building a mountain of fire

Feeling hot, hot, hot

The temperature of lava can range from anything between 700 and 1,300°C

Image courtesy of the US Geological Survey

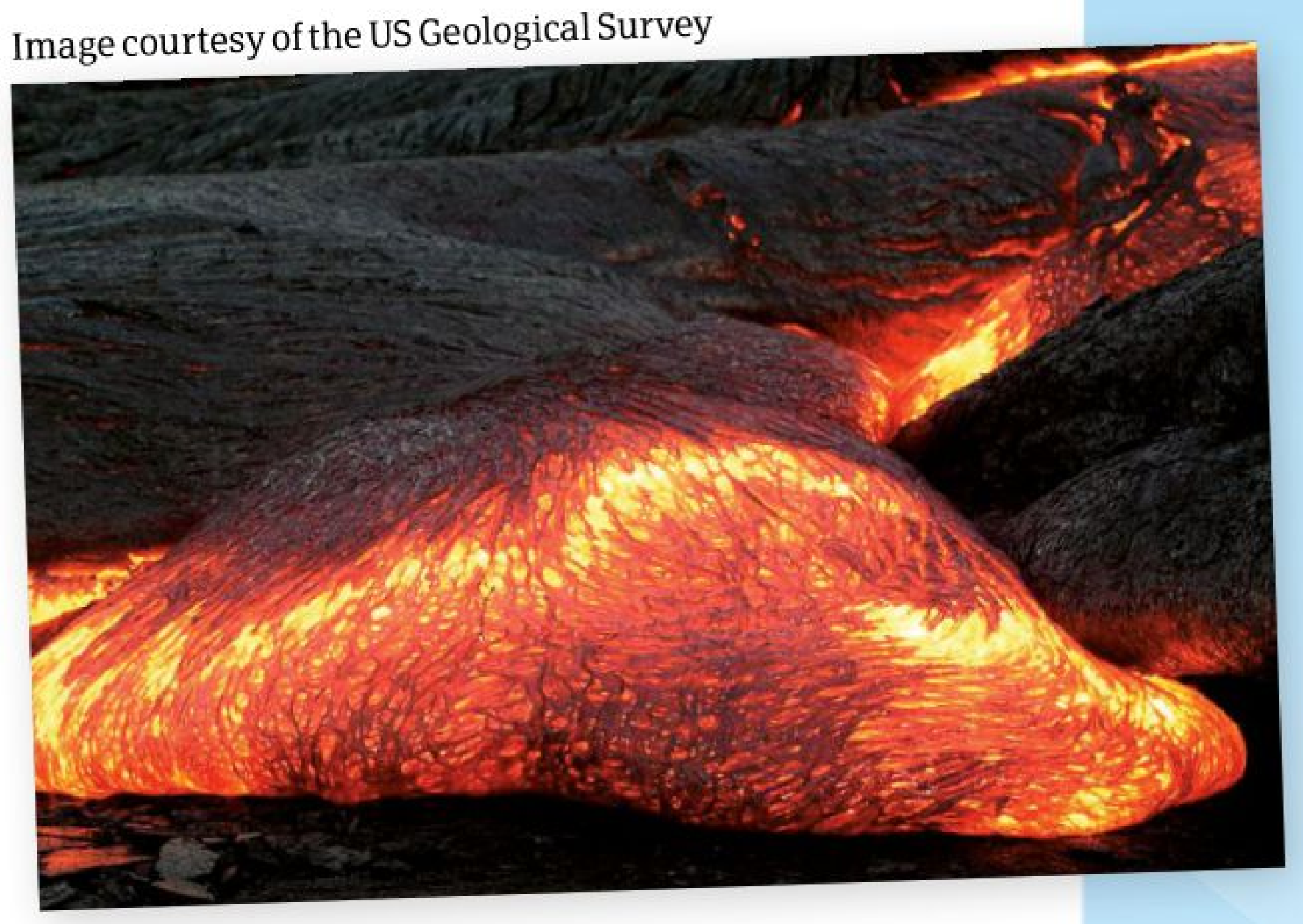
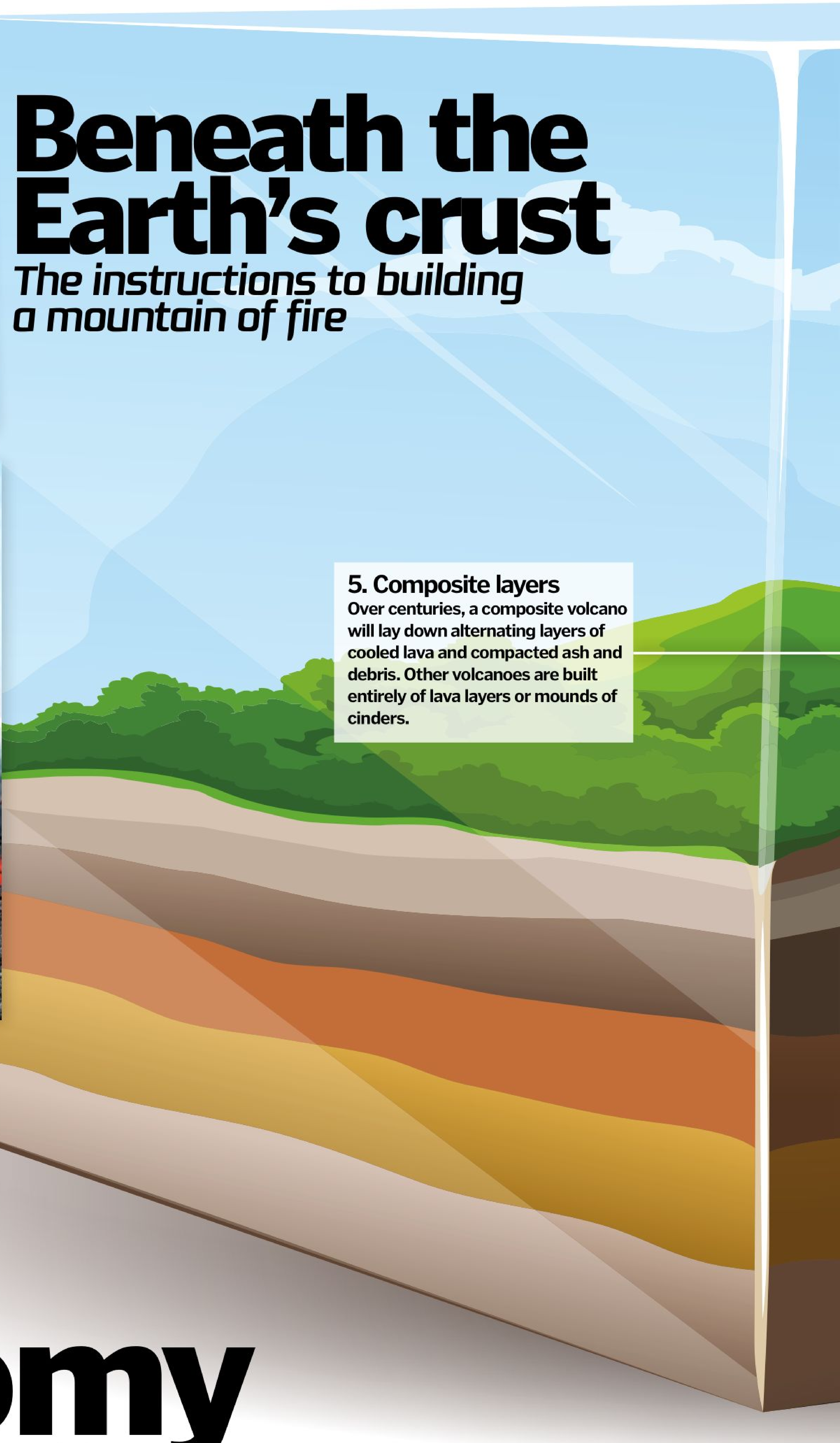


Image courtesy of the US Geological Survey

The wow factor

Although deadly, an erupting volcano is one of nature's most stunning sights



5. Composite layers

Over centuries, a composite volcano will lay down alternating layers of cooled lava and compacted ash and debris. Other volcanoes are built entirely of lava layers or mounds of cinders.

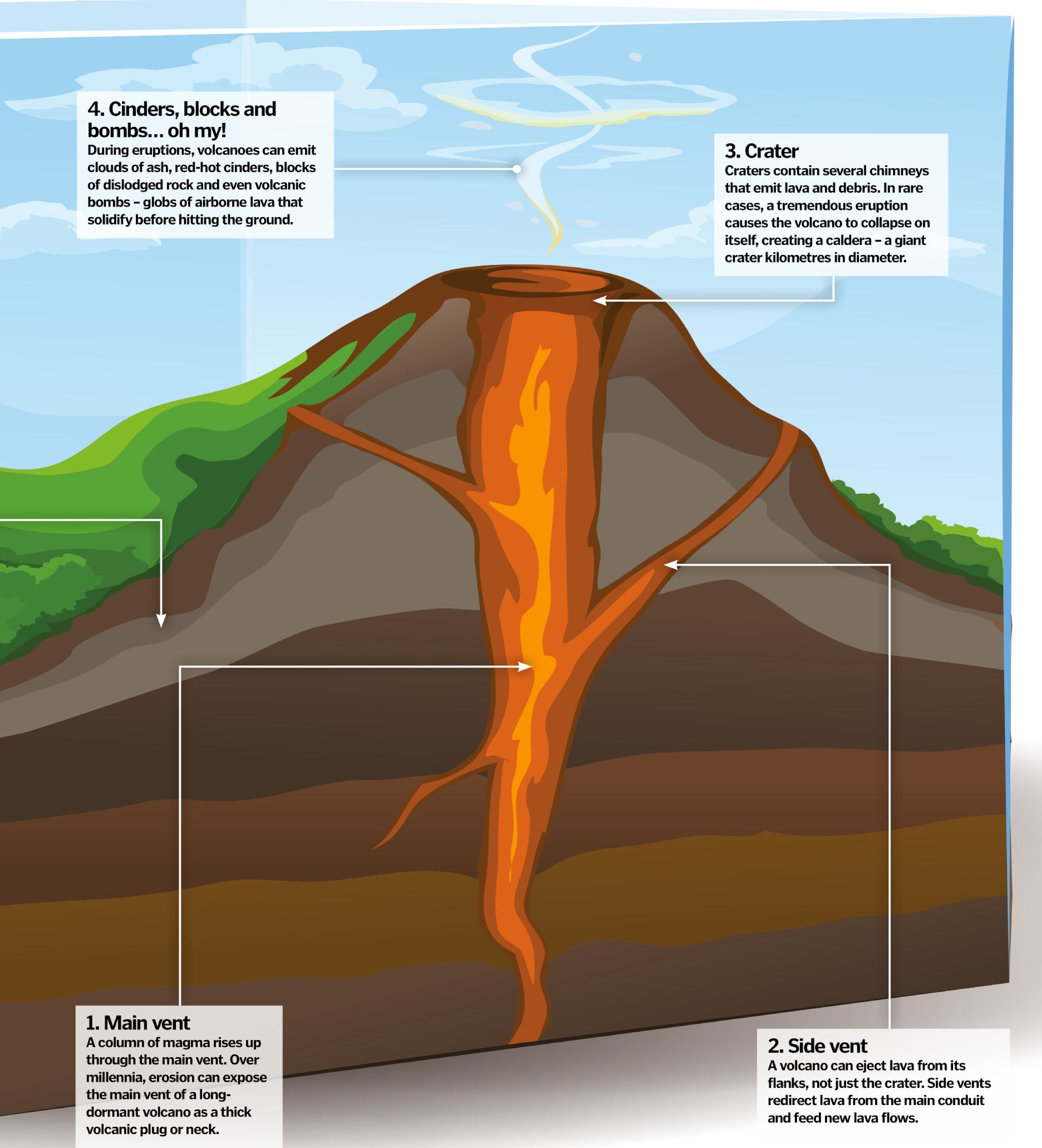
Anatomy of a volcano

Volcanoes are rare locations on the Earth's crust where molten rock (magma) spews to the surface as lava, often accompanied by superheated gas and debris.

Geologists see volcanoes as outward evidence of the inner workings of plate tectonics, the theory that the crust is fragmented into 15 oceanic and continental plates that diverge, converge and slide beneath one another over time.

Approximately 400 of Earth's 500 known active volcanoes lie atop subduction zones, places where an oceanic plate slips beneath another oceanic or continental plate. The 'Ring of Fire' traces a circle of highly active subduction zones around the Pacific Ocean.

In a subduction volcano, magma is formed 100 to 200km beneath the surface when water and carbon dioxide seep from the sinking oceanic shelf, lowering the melting point



1. Main vent

A column of magma rises up through the main vent. Over millennia, erosion can expose the main vent of a long-dormant volcano as a thick volcanic plug or neck.

2. Side vent

A volcano can eject lava from its flanks, not just the crater. Side vents redirect lava from the main conduit and feed new lava flows.

3. Crater

Craters contain several chimneys that emit lava and debris. In rare cases, a tremendous eruption causes the volcano to collapse on itself, creating a caldera – a giant crater kilometres in diameter.

4. Cinders, blocks and bombs… oh my!

During eruptions, volcanoes can emit clouds of ash, red-hot cinders, blocks of dislodged rock and even volcanic bombs – globs of airborne lava that solidify before hitting the ground.

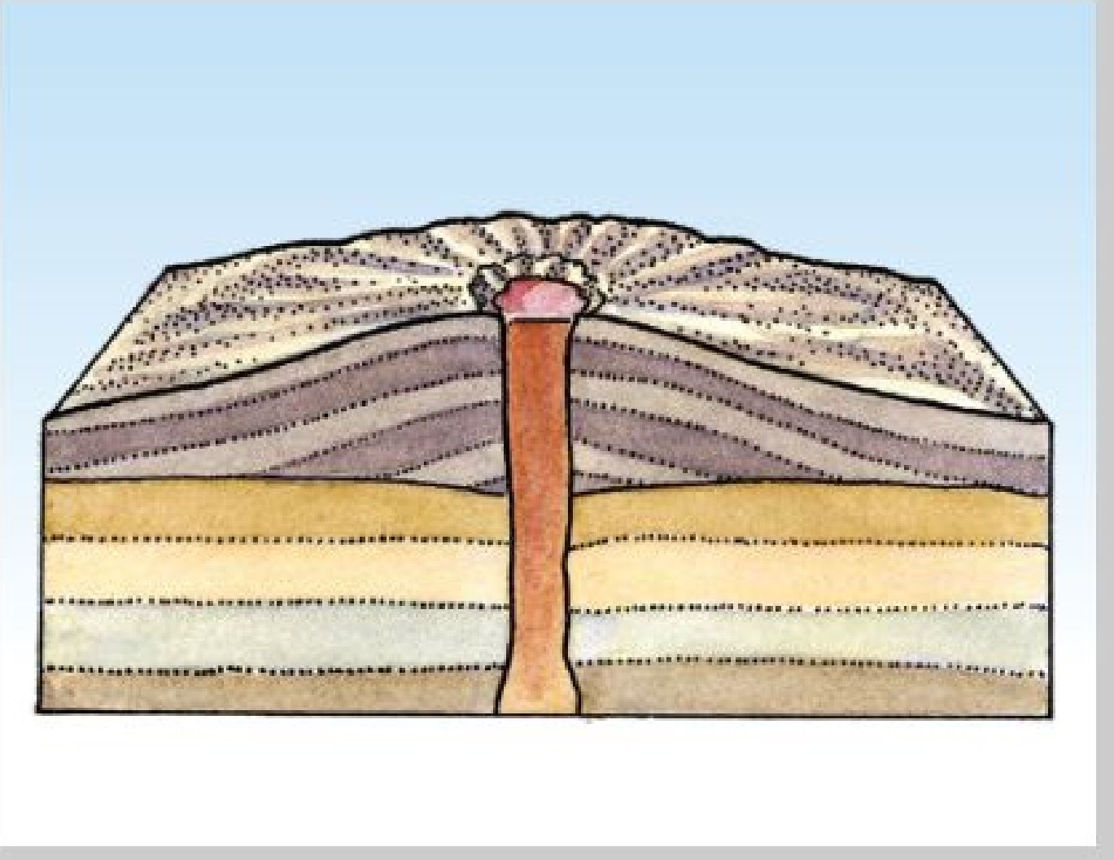
Breathtaking and often devastating reminders that the Earth's surface is actively evolving

of the surrounding rock. This fresh magma, which is lighter than solid rock, percolates upward through fissures in the crust, eventually exploding to the surface when trapped gases in the magma rush to escape.

Rift volcanoes form along the great seams of two separating plates. The mid-Atlantic ridge, which separates the North American and African plates, is one of these seams. As the plates pull apart, magma bubbles up through hundreds, even thousands, of small volcanoes to fill the cracks, creating new ocean floor. Five per cent of volcanoes are located far from the seams of tectonic plates. So-called hot spot volcanoes are fuelled by deep sources of magma pumped to the surface through powerful convection currents in the molten mantle. Since the deep fuel source remains fixed while the plate slides above, the result is often a string of volcanoes.

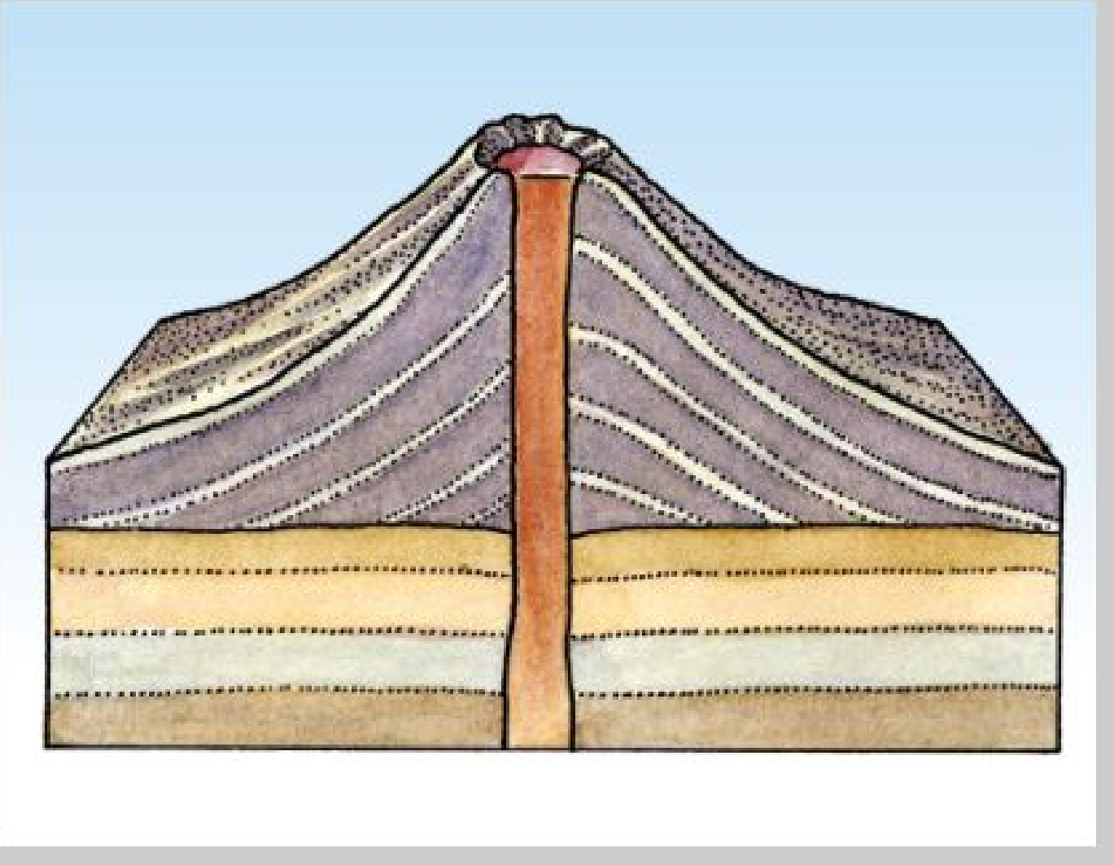
TYPES OF… Volcanoes

Volcanism takes the shape of towering peaks and flat plateaus



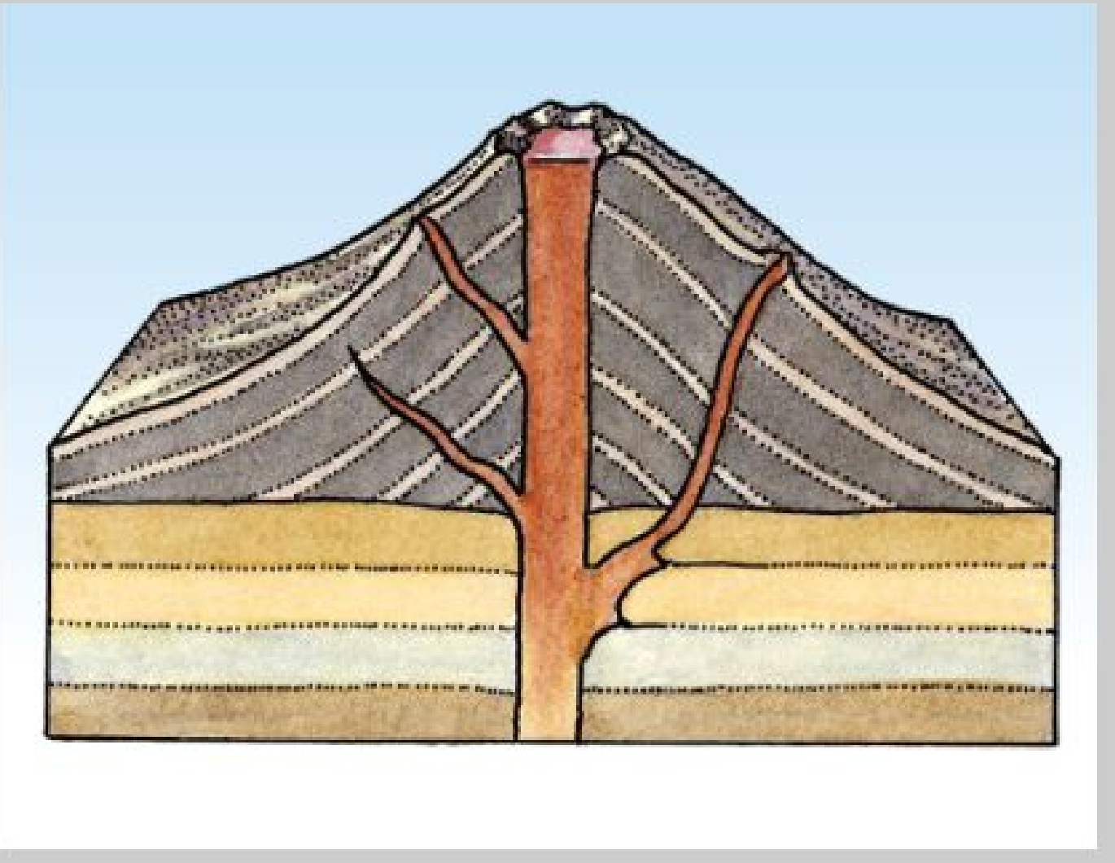
Shield

Wide, shallow-sloped volcanoes formed by layers of slow-oozing lava (Mauna Loa in Hawaii).



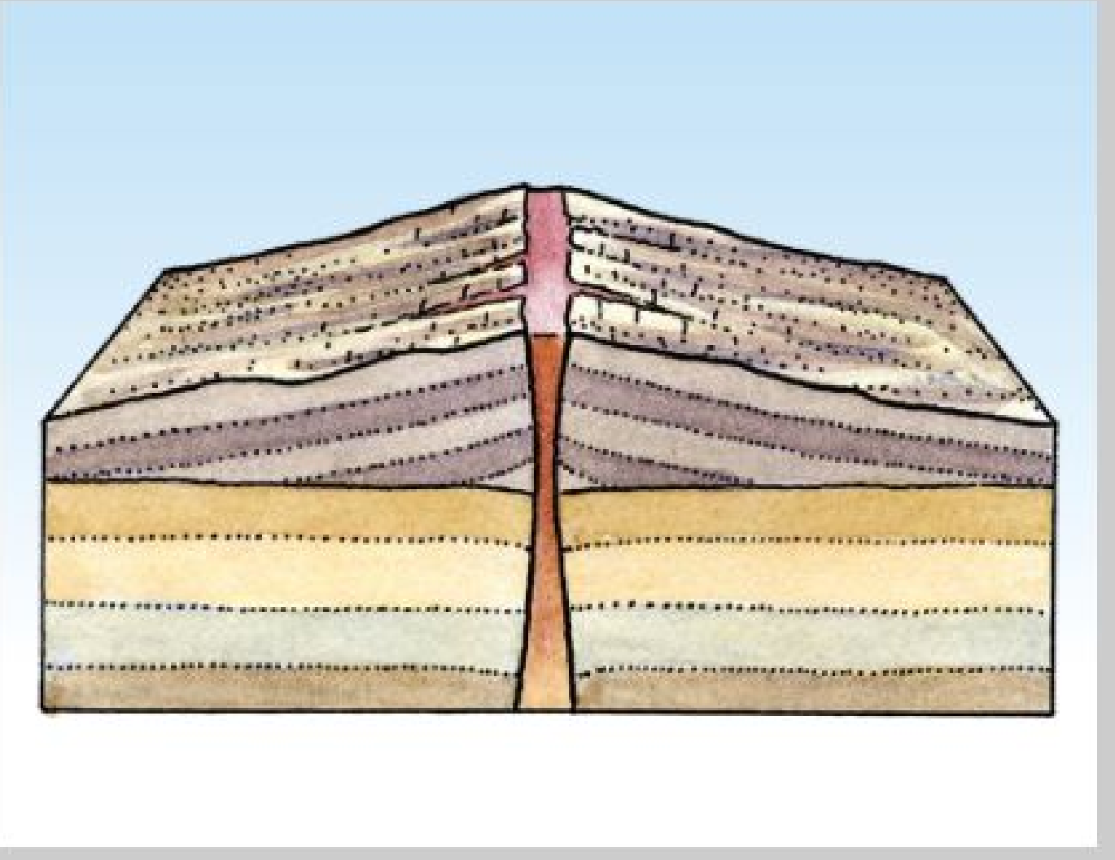
Cinder

Small, single-vent volcanoes composed of a pile of shattered volcanic rock and ash (Paricutín in Mexico).



Composite

Tall, steep-sloped volcanoes made from alternating layers of cooled lava and debris like ash and lava bombs (Mt Fuji in Japan).

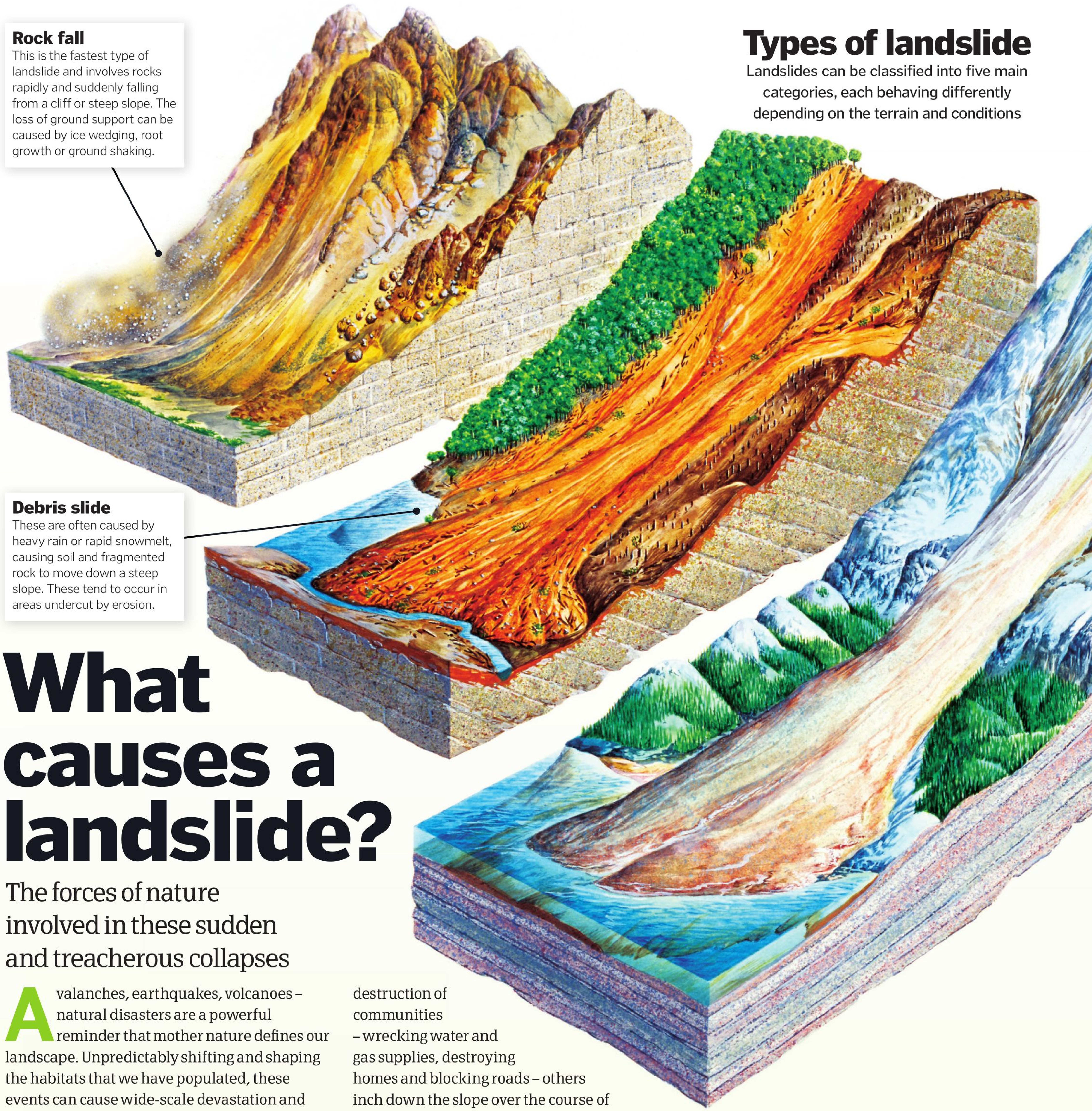


Fissure

Flat fields of lava that emerge from long cracks along the Earth's rift zones (Las Pilas in Nicaragua).

Learn more

For more information about volcanoes visit **www.avo.alaska.edu**, the official website of the Alaska Volcano Observatory, where you can see videos and live webcams of all the active volcanos in Alaska.



Types of landslide

Landslides can be classified into five main categories, each behaving differently depending on the terrain and conditions

Rock fall
This is the fastest type of landslide and involves rocks rapidly and suddenly falling from a cliff or steep slope. The loss of ground support can be caused by ice wedging, root growth or ground shaking.

Debris slide
These are often caused by heavy rain or rapid snowmelt, causing soil and fragmented rock to move down a steep slope. These tend to occur in areas undercut by erosion.

What causes a landslide?

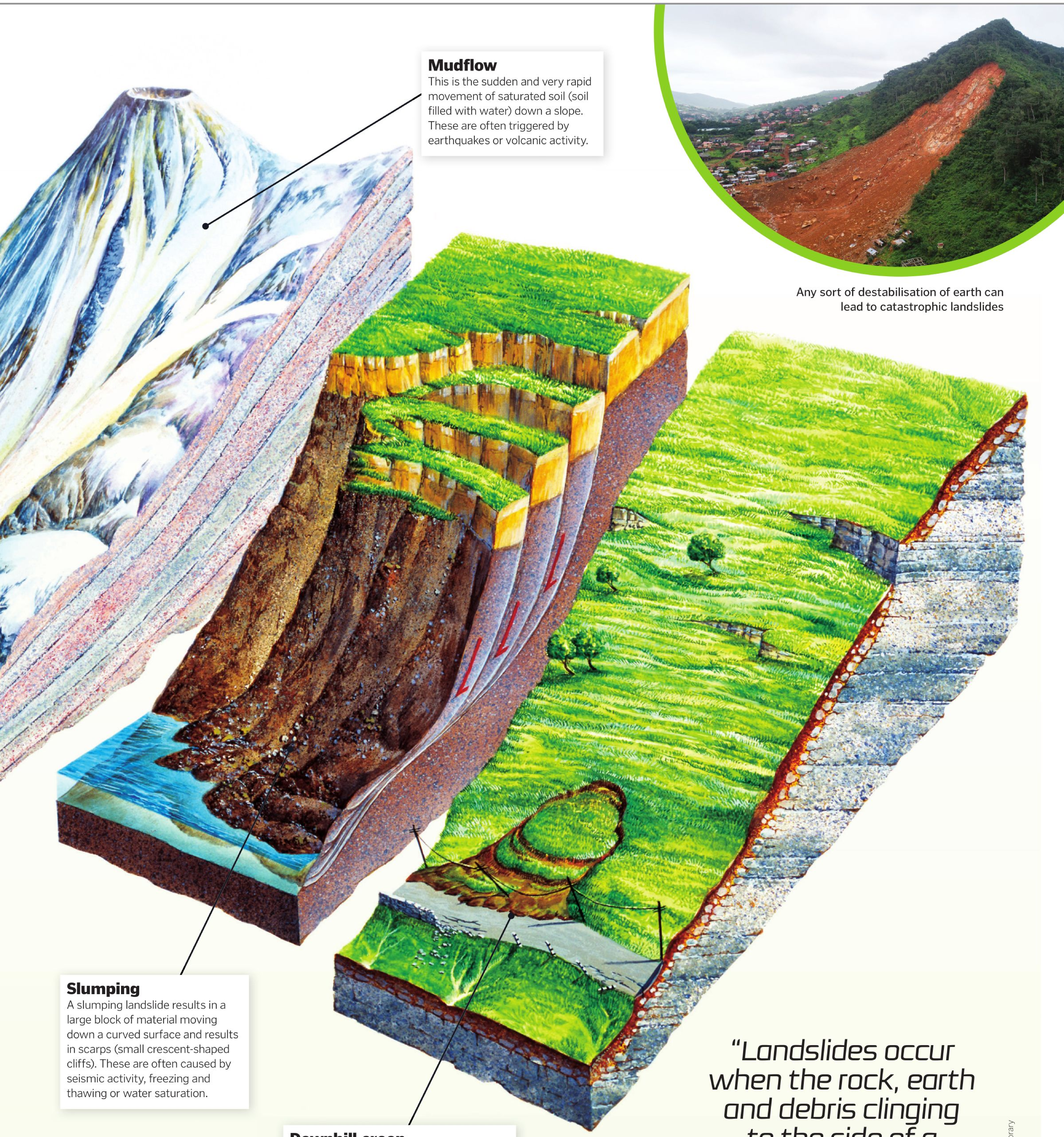
The forces of nature involved in these sudden and treacherous collapses

Avalanches, earthquakes, volcanoes – natural disasters are a powerful reminder that mother nature defines our landscape. Unpredictably shifting and shaping the habitats that we have populated, these events can cause wide-scale devastation and dramatic changes on the Earth's surface. Landslides are one of these natural disasters.

The term 'landslide' describes a category of mass movement that happens on cliffs and mountain faces. They occur when the rock, earth and debris clinging to the side of a mountain or slope succumb to the forces of gravity. While some types of landslide hurtle towards the ground and result in catastrophic destruction of communities – wrecking water and gas supplies, destroying homes and blocking roads – others inch down the slope over the course of years. Seismic activity and weather conditions like extreme rainfall have been shifting soil for millennia, but increased human activity means they are occurring even more frequently.

One of the most commonly observed causes of landslides occurs when cliffs or mountains become heavily saturated. The soil can slip more easily in areas of deforestation, for example, because there is no root system to protect against erosion. Clear-cutting methods of timber harvesting, which pull up existing root structures, increase the likelihood of a landslide occurring. Mining with detonation techniques, which generates strong vibrations that shudder through the ground, can also enhances the risk of a landslip.

DID YOU KNOW? *A lahar is a destructive type of mudslide that travels down the side of a volcano at speeds of over 80kph*



Any sort of destabilisation of earth can lead to catastrophic landslides

Mudflow
This is the sudden and very rapid movement of saturated soil (soil filled with water) down a slope. These are often triggered by earthquakes or volcanic activity.

Slumping
A slumping landslide results in a large block of material moving down a curved surface and results in scarps (small crescent-shaped cliffs). These are often caused by seismic activity, freezing and thawing or water saturation.

Downhill creep
This is a slow, downward progression of earth caused by numerous tiny movements that create permanent deformations of the land. They can lead to broken walls, leaning poles and curved tree trunks.

"Landslides occur when the rock, earth and debris clinging to the side of a mountain succumb to the forces of gravity"

© Getty; Science Photo Library

Humpback whales

Discover the amazing anatomy of one of Earth's biggest mammals

Longer than a London bus and weighing more than four African elephants, humpback whales are true giants of the ocean. In the harsh conditions of the sea, humpbacks are anatomically adapted to life under the waves. As one of over ten baleen whale species, humpbacks have an interesting way of feeding. Within the whale's mouth are around 600 baleen plates made from keratin, the same protein that forms our hair and nails. These plates, together with hairs, act like a sieve through which they filter their daily consumption of around one ton of plankton, flushed in by the surrounding water.

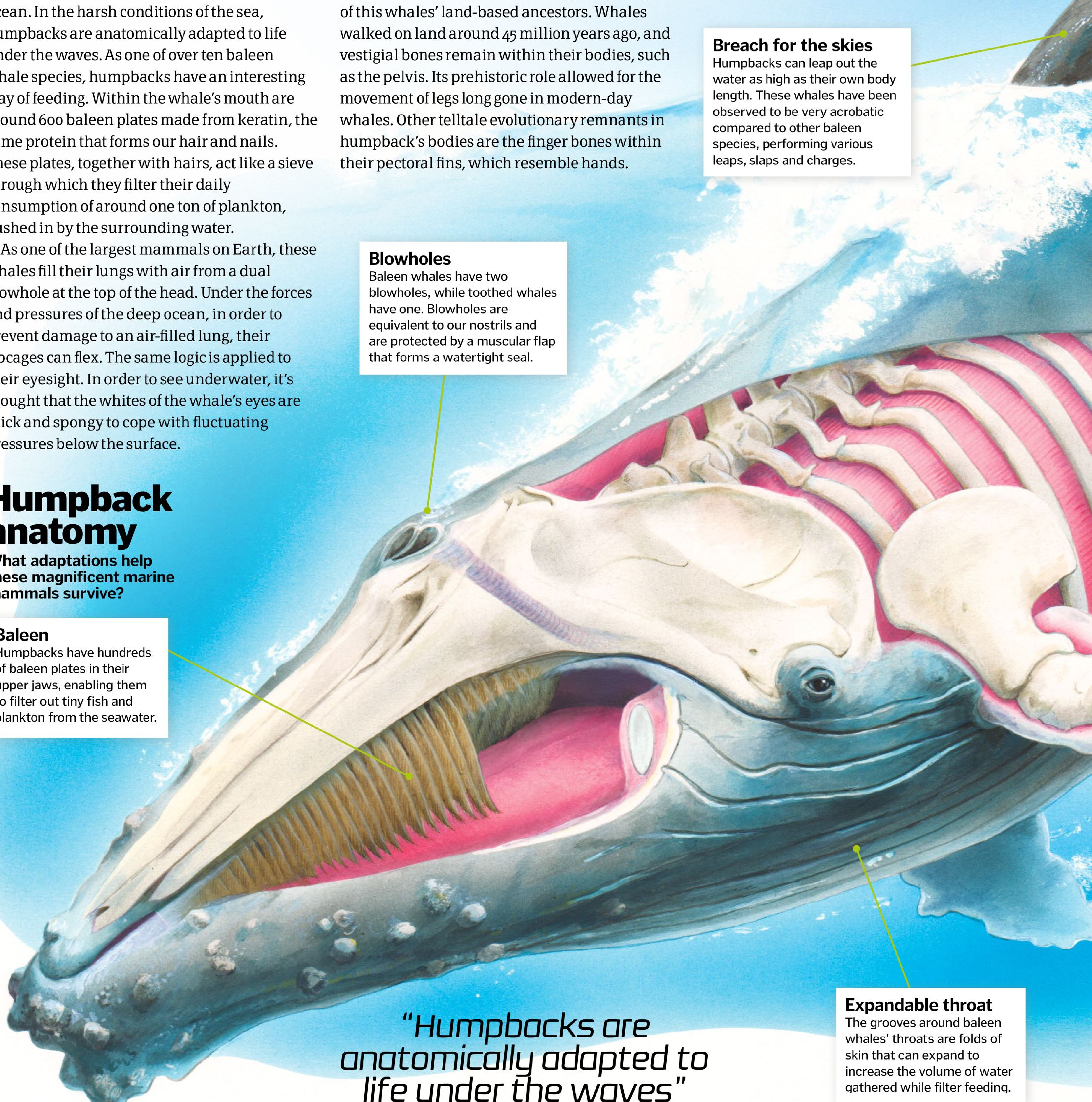
As one of the largest mammals on Earth, these whales fill their lungs with air from a dual blowhole at the top of the head. Under the forces and pressures of the deep ocean, in order to prevent damage to an air-filled lung, their ribcages can flex. The same logic is applied to their eyesight. In order to see underwater, it's thought that the whites of the whale's eyes are thick and spongy to cope with fluctuating pressures below the surface.

Beneath their blubber, which can be more than 40 centimetres thick after feeding all summer, lies a skeleton displaying unique signs of this whales' land-based ancestors. Whales walked on land around 45 million years ago, and vestigial bones remain within their bodies, such as the pelvis. Its prehistoric role allowed for the movement of legs long gone in modern-day whales. Other telltale evolutionary remnants in humpback's bodies are the finger bones within their pectoral fins, which resemble hands.

Humpbacks are well known for their love of cetacean surfacing behaviour, or breaching

Humpback anatomy

What adaptations help these magnificent marine mammals survive?



Breach for the skies
Humpbacks can leap out the water as high as their own body length. These whales have been observed to be very acrobatic compared to other baleen species, performing various leaps, slaps and charges.

Blowholes
Baleen whales have two blowholes, while toothed whales have one. Blowholes are equivalent to our nostrils and are protected by a muscular flap that forms a watertight seal.

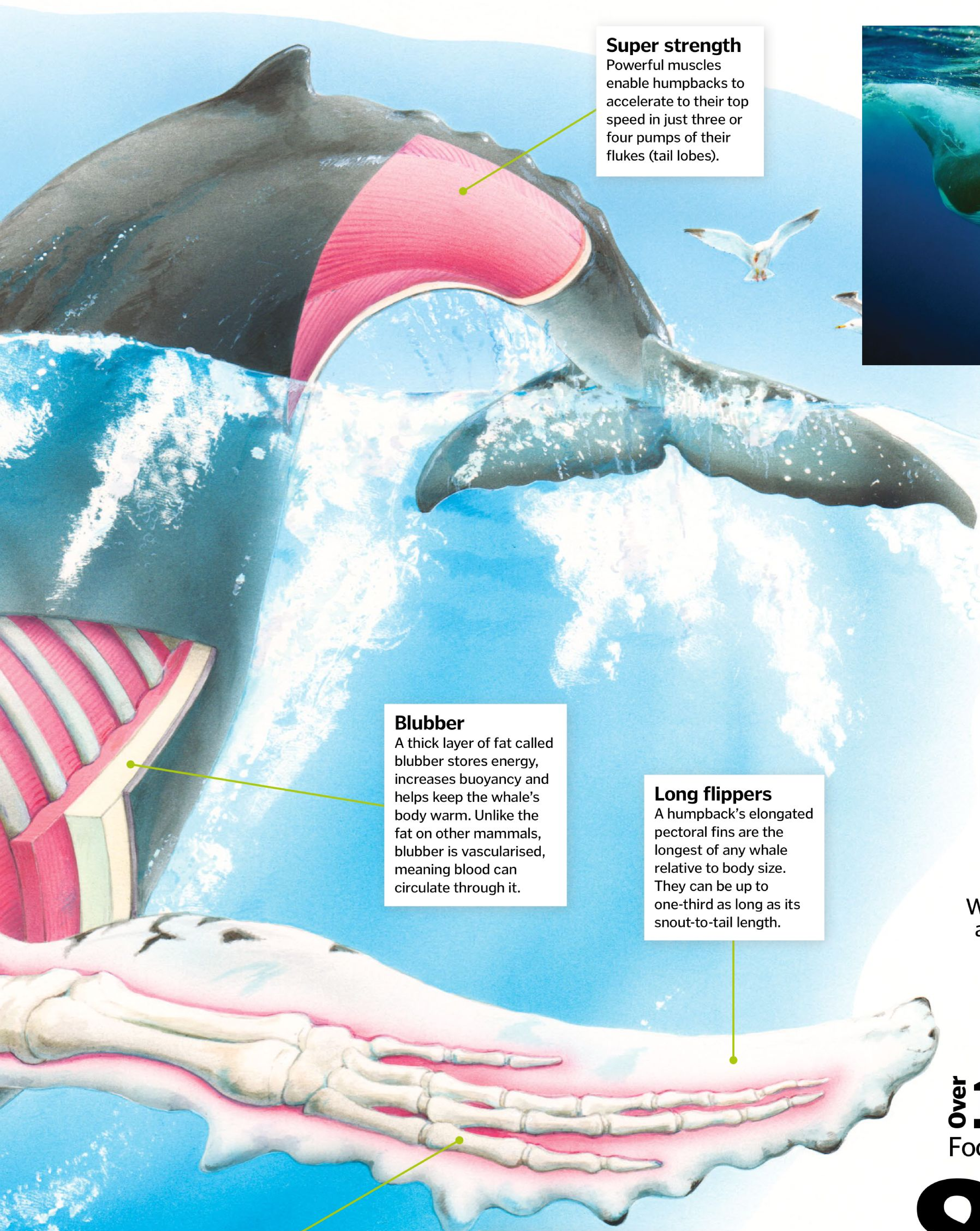
Baleen
Humpbacks have hundreds of baleen plates in their upper jaws, enabling them to filter out tiny fish and plankton from the seawater.

Expandable throat
The grooves around baleen whales' throats are folds of skin that can expand to increase the volume of water gathered while filter feeding.

> "Humpbacks are anatomically adapted to life under the waves"

© Alamy; Getty; Thinkstock

DID YOU KNOW? *The closest living genetic relative to whales is the hippopotamus*



Super strength
Powerful muscles enable humpbacks to accelerate to their top speed in just three or four pumps of their flukes (tail lobes).

Blubber
A thick layer of fat called blubber stores energy, increases buoyancy and helps keep the whale's body warm. Unlike the fat on other mammals, blubber is vascularised, meaning blood can circulate through it.

Long flippers
A humpback's elongated pectoral fins are the longest of any whale relative to body size. They can be up to one-third as long as its snout-to-tail length.

Ancestral remnants
Whales are mammals and still carry some terrestrial anatomical features from their land-living ancestors, such as finger bones.

Humpback whales have been seen to cluster, or herd, plankton shoals

Humpback stats

5m
Flipper length

Up to 18m
Length of an average adult body

30 tons
Weight of average adult

Over 1.3 tons
Food consumed per day

80 years
Life expectancy

32 KM
The distance calls can travel

18,841km
Record migration distance

Barnacles can often be seen hitching a ride on the fins of humpbacks

How wells work

Groundwater is an important source of fresh water for people all over the world

Our planet has an abundance of water, and it is the source of all life on Earth, but when you pour yourself a refreshing drink of cold water from the tap, you probably don't think of the kilometres it has travelled from its source to your glass.

More than 70 per cent of our planet is covered in water, and a large portion of fresh water is stored beneath the surface as groundwater. This groundwater can be accessed by building wells – something humans first started doing around 8,000 years ago in the Neolithic period. These were mostly hand-dug wells, a method still relied upon by millions of people living in rural areas of developing countries. However, many hand-dug wells are now having pumps added to their systems or are being built deeper as a result of more sophisticated methods that make extracting the water a much more efficient process than it once was.

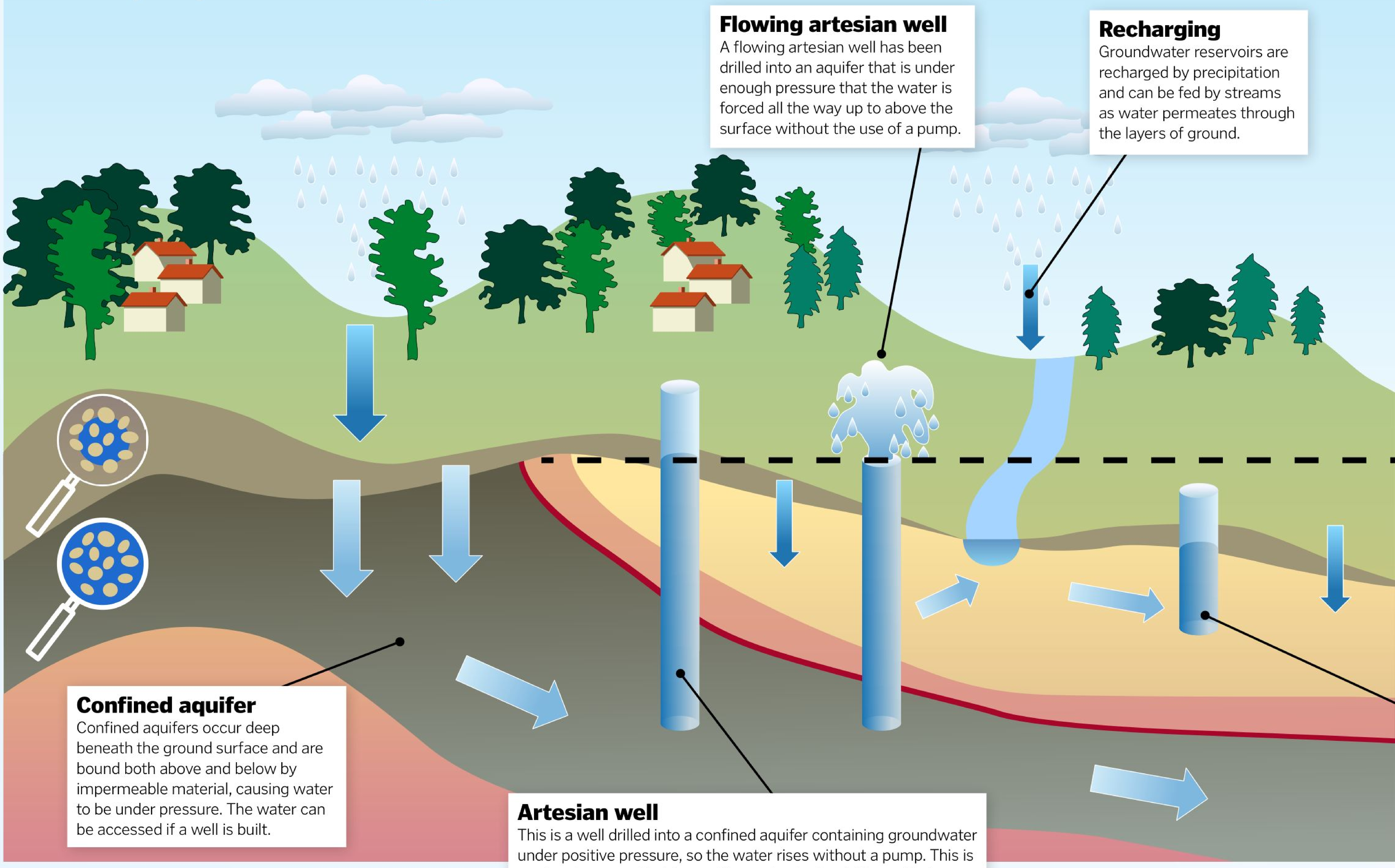
Wells accessing groundwater reservoirs provide 25 to 40 per cent of the world's drinking water. The reservoirs of water are stored under the surface in aquifers. Some aquifers are closer to the surface and are regularly replenished directly by rain (or melted snow) seeping into the ground, while others deeper in the ground may take longer to replenish as they gain their source from aquifers higher up. Many of these reservoirs were recharged in ancient times over thousands of years, making them renewable sources of water. Wells are built into these aquifers using different methods to access the drinkable water below.

Wells are particularly vital for those who live in remote villages without modern water supply systems

> "More than 70 per cent of our planet is covered in water, and a large portion is groundwater"

Wells, aquifers and groundwater

What underground water sources exist and how do we access them?



Flowing artesian well
A flowing artesian well has been drilled into an aquifer that is under enough pressure that the water is forced all the way up to above the surface without the use of a pump.

Recharging
Groundwater reservoirs are recharged by precipitation and can be fed by streams as water permeates through the layers of ground.

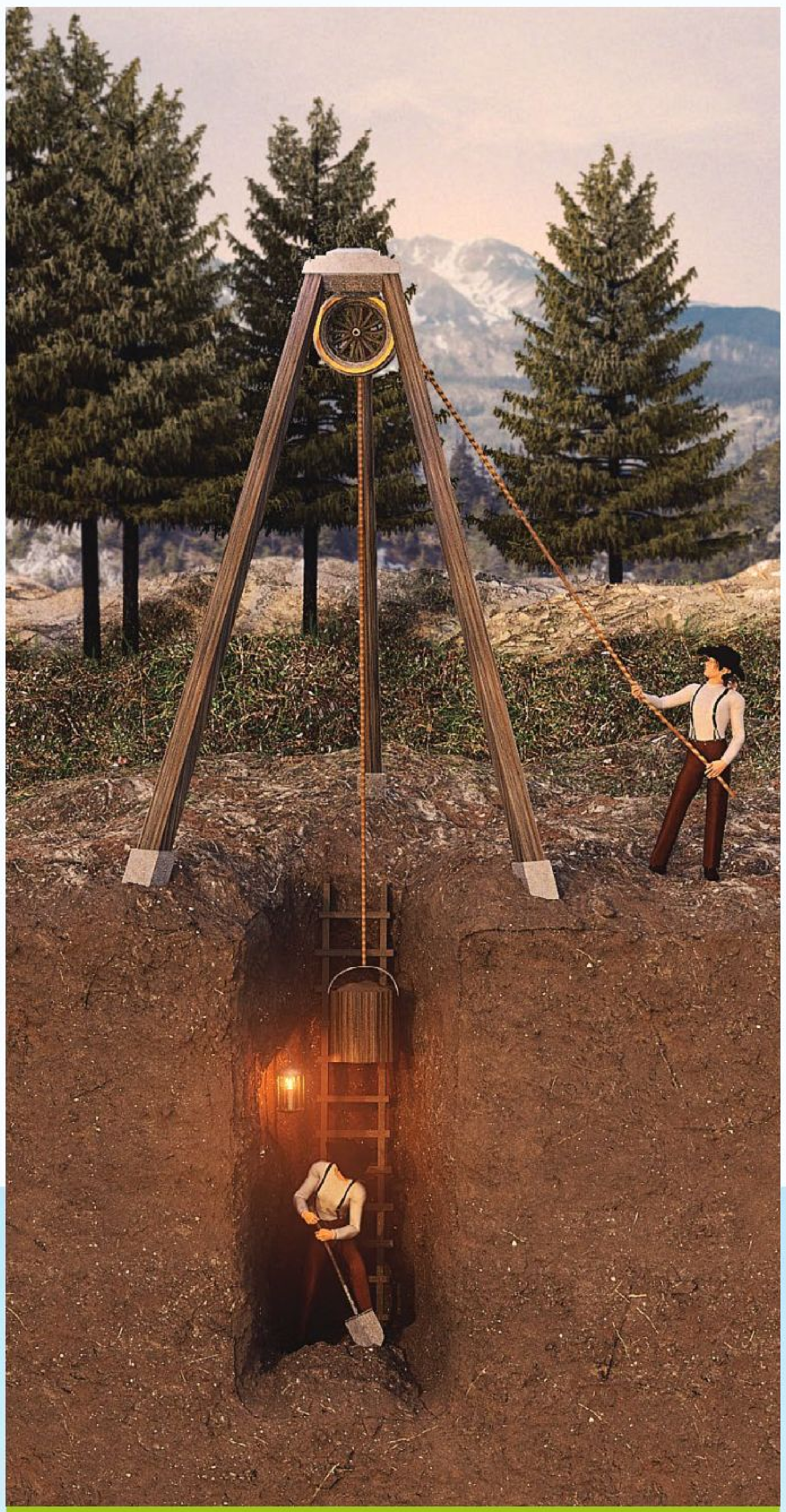
Confined aquifer
Confined aquifers occur deep beneath the ground surface and are bound both above and below by impermeable material, causing water to be under pressure. The water can be accessed if a well is built.

Artesian well
This is a well drilled into a confined aquifer containing groundwater under positive pressure, so the water rises without a pump. This is a natural process that is used to reach a hydrostatic equilibrium, but the water does not necessarily reach the surface.

DID YOU KNOW? *Around 68.7 per cent of Earth's fresh water is trapped within glaciers and ice caps*

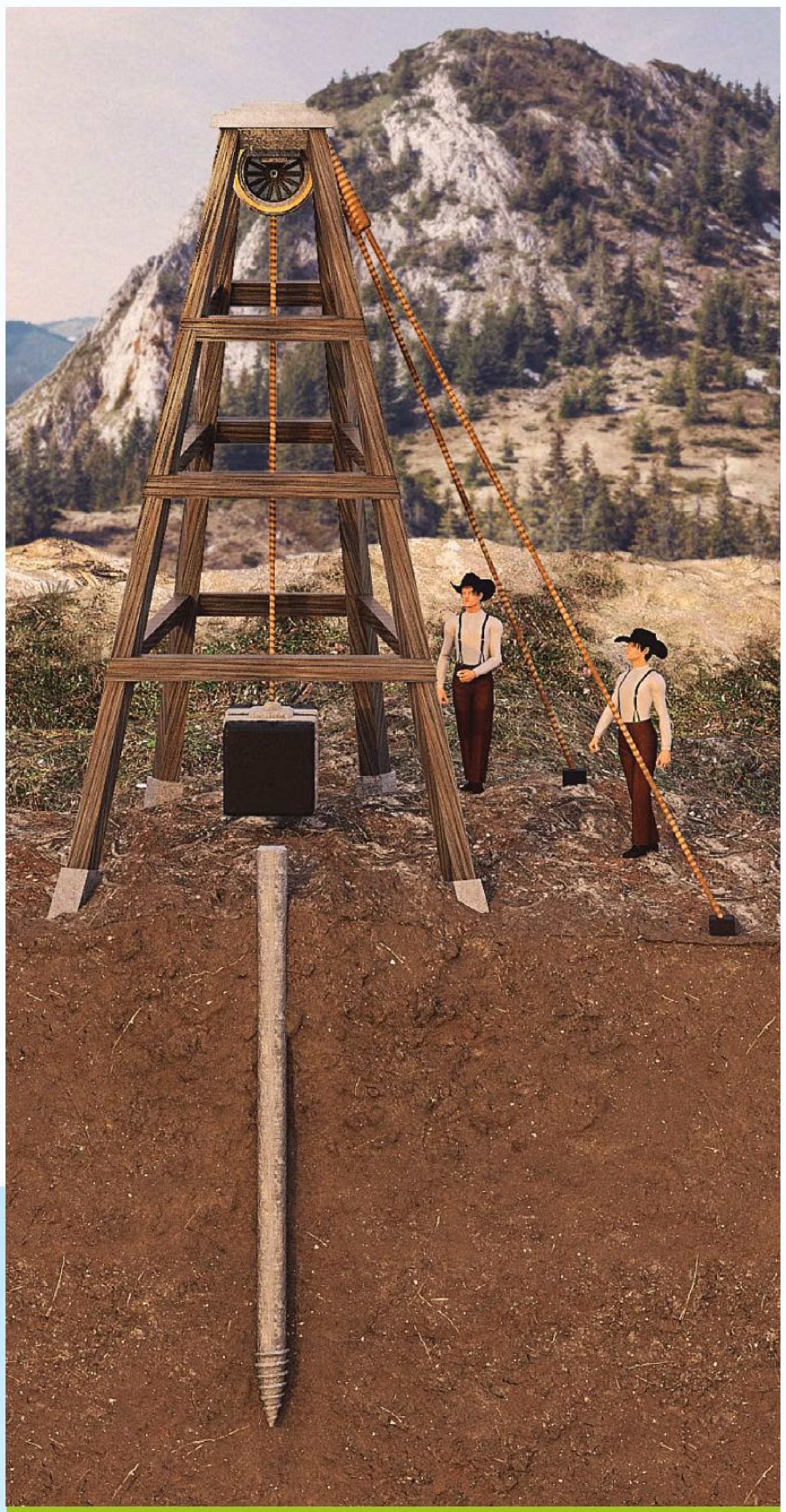
Building wells

There are three main ways to dig for water…



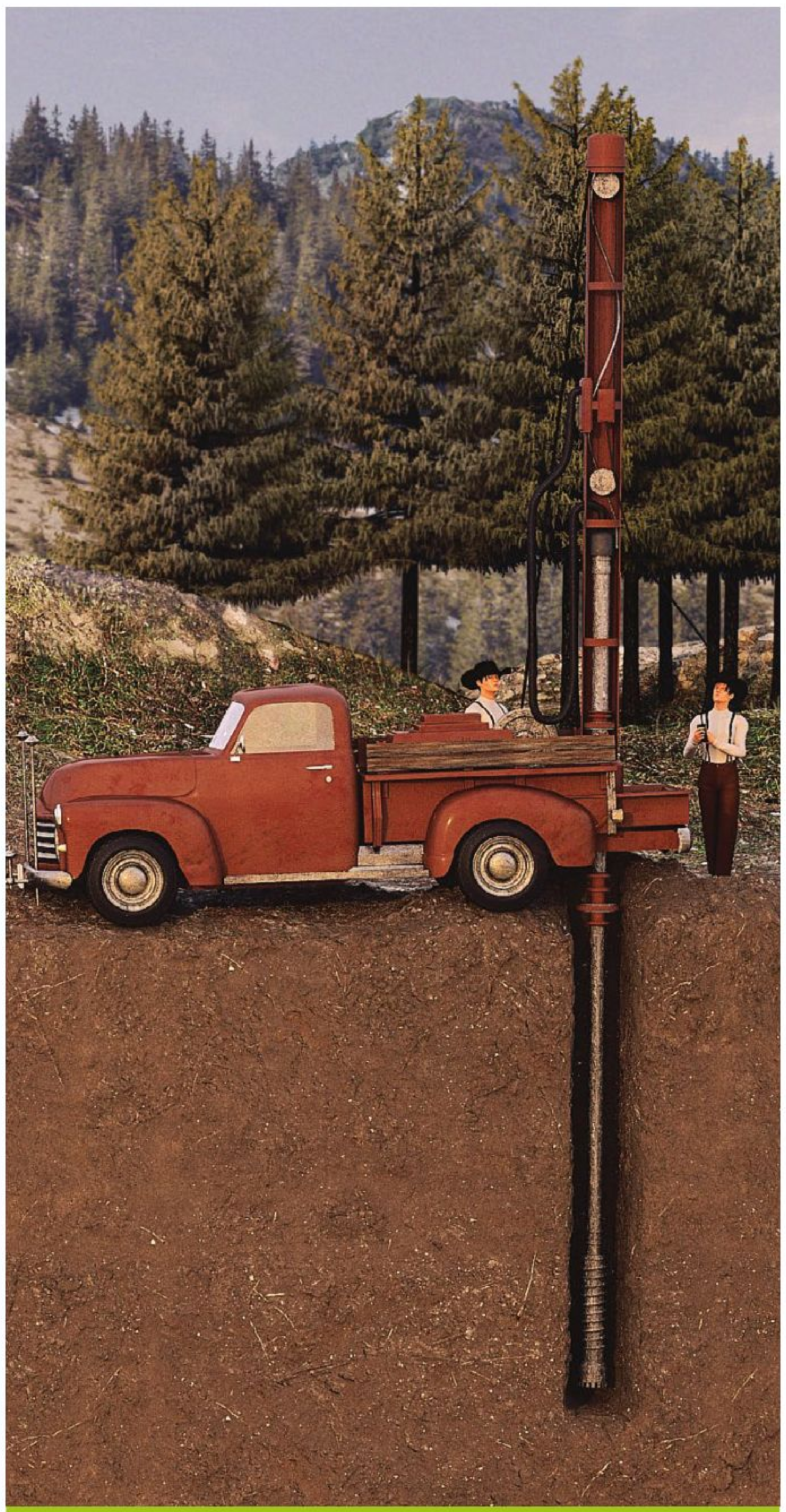
Dug

Dug wells are constructed below the groundwater table using a shovel. They are generally deepened until the digger finds water is filling the hole faster than they can bail it out. It is then lined with hard material to support it.



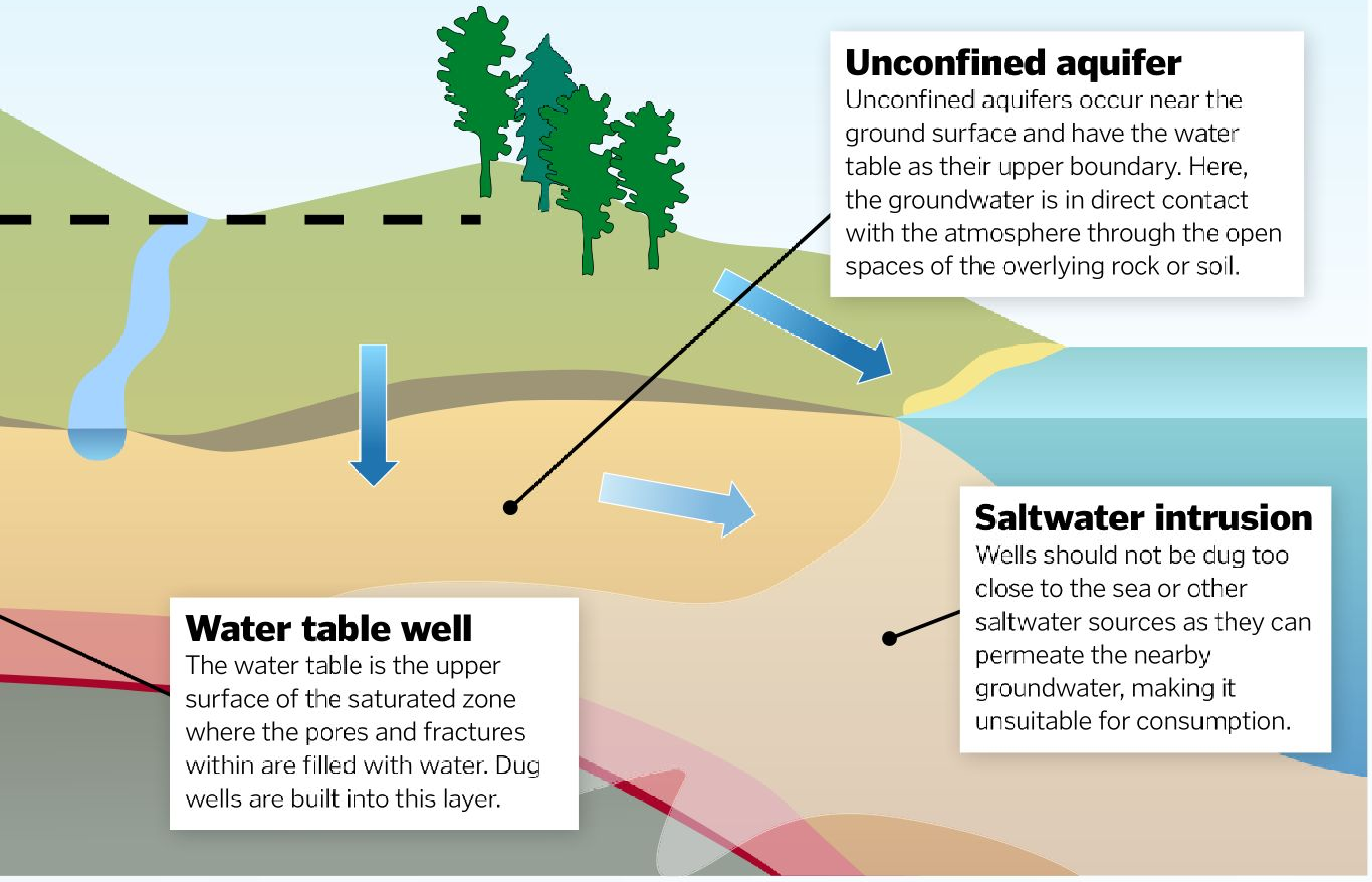
Driven

A driven well is smaller in diameter and built by assembling thin lengths of steel pipe. Each section – a couple of metres long – is screwed together and driven into the ground up to a depth of around nine metres.



Drilled

A drilled well is a hole bored into the ground. A lined casing is installed around the upper part of the well to prevent collapse and to stop surface or subsurface contaminants from entering the water supply.



Unconfined aquifer

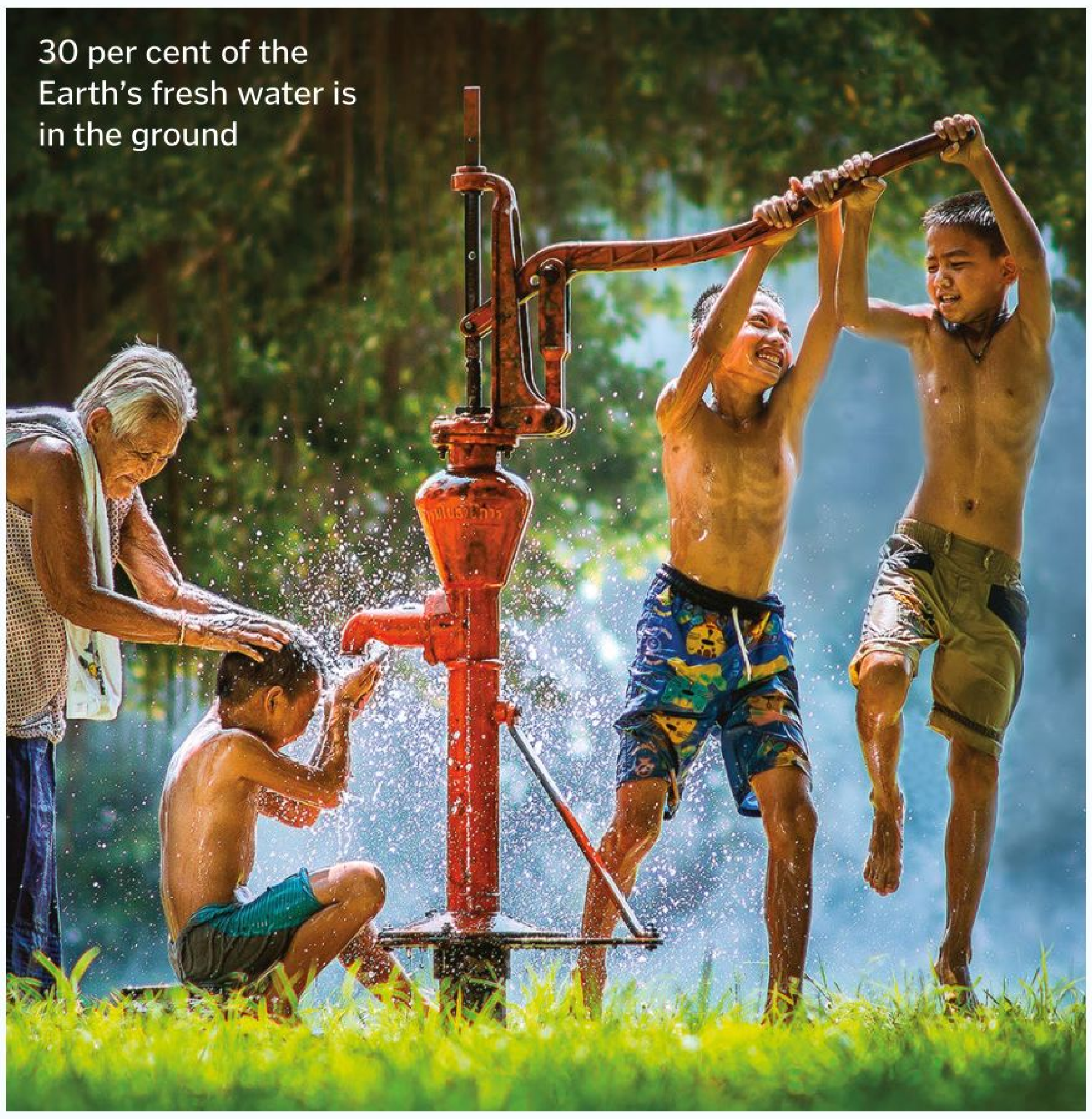
Unconfined aquifers occur near the ground surface and have the water table as their upper boundary. Here, the groundwater is in direct contact with the atmosphere through the open spaces of the overlying rock or soil.

Saltwater intrusion

Wells should not be dug too close to the sea or other saltwater sources as they can permeate the nearby groundwater, making it unsuitable for consumption.

Water table well

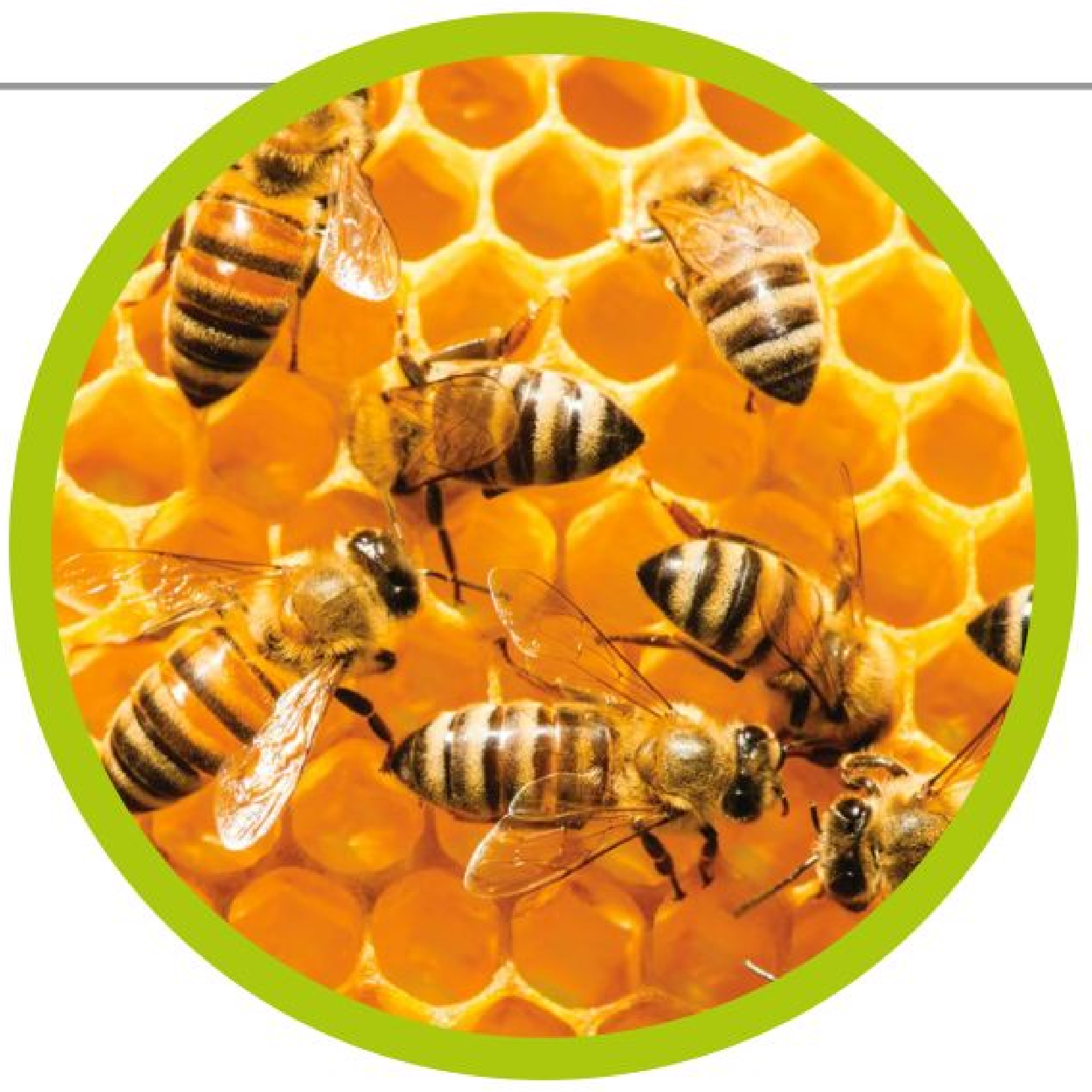
The water table is the upper surface of the saturated zone where the pores and fractures within are filled with water. Dug wells are built into this layer.



30 per cent of the Earth's fresh water is in the ground

© Getty; Illustrations by Adrian Mann / Nicholas Forder

A buzzing business



A single colony of bees can have tens of thousands of members

How do honeybees manufacture honey and why do they make it?

It's a well-known fact that honeybees make the silky, golden delight that is honey, but how exactly is it manufactured? Zipping from one flower to another, honeybees perch themselves on petals and extract the sweet nectar within. It is here that the production of honey begins.

Storing the nectar in a separate 'honey stomach', enzymes within start transforming nectar into the beginnings of honey. Known as the 'bee enzyme', or invertase, it converts the sucrose sugar in nectar into simple sugars – glucose and fructose. Upon returning from their forage, these bees will regurgitate the contents of their honey stomach, giving it to other worker bees in the hive. These bees will then process the sugary solution by repeating the process of ingestion and regurgitation until their enzymes complete the conversion. This sugary solution is much less viscous than the thick honey we recognise spread on our toast.

Honey only contains around 17 per cent water. Therefore, in order to remove the excess water, bees continually beat their wings to dry it out. Once completely processed, the product is stored in the iconic hexagonal cells within the hive. The trick to keeping long-lasting honey is to store it in an airtight location, thereby reducing the possibility of contamination. Bees will seal the honey in each cell with beeswax, which is secreted from specialised glands on their abdomens.

This systematic approach to production mirrors that of our own manufacturing lines, but why do they even make honey? After all, they don't naturally do it to feed human demand.

Unlike their close relatives, the bumblebee and wasp, honeybees do not hibernate during the winter months. This means that they will require a source of nutrients when food isn't readily available. Therefore they continuously produce honey – provided there is still space for it in the hive – in order to sustain themselves once flower nectar is taken away with the end of summer.

> *"This systematic approach to production mirrors that of our own manufacturing lines"*

Past its 'cell-by' date?

One of the oldest examples of honey was discovered in an ancient Egyptian tomb. Incredibly, it was still edible, which begs the question of why honey doesn't spoil. The answer lies in two main properties of honey.

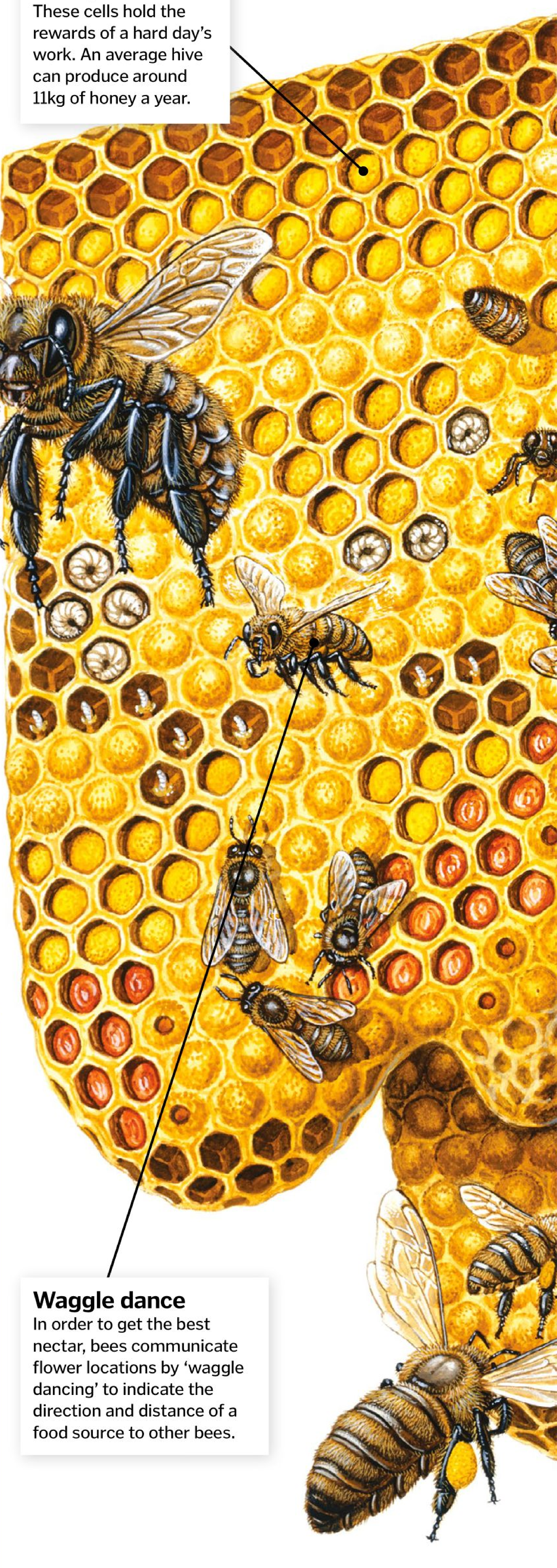
The first is its lack of water. In order for microbial growth to occur a certain level of water is required, which is known as a substance's water activity. At around 17 per cent water, honey has a water activity of 0.60: bacteria and fungi require an activity of around 0.91 and 0.70 respectively in order to survive.

Acidity is the other key factor in the preservation of this golden wonder. Honey has an average pH of 3.9, which prevents bacteria from growing in this acidic environment. This all means that honey can last for over 3,000 years, as proven by the examples left by the sweet-toothed Egyptians who produced it all those millennia ago.

Scientists are investigating whether honey's antimicrobial properties could help in the fight against drug-resistant bacteria

The honey factory

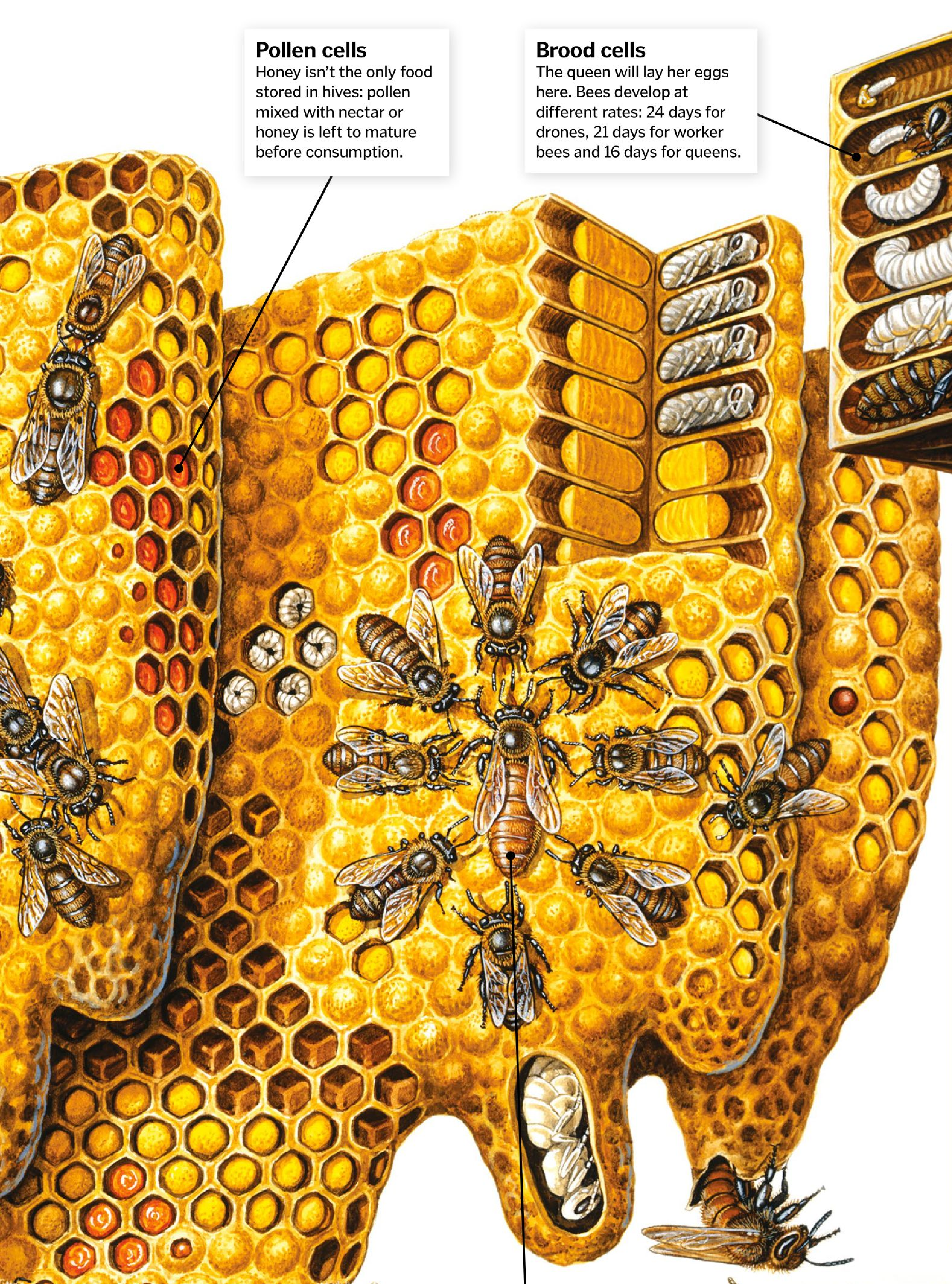
What makes up the busy business of honey production?

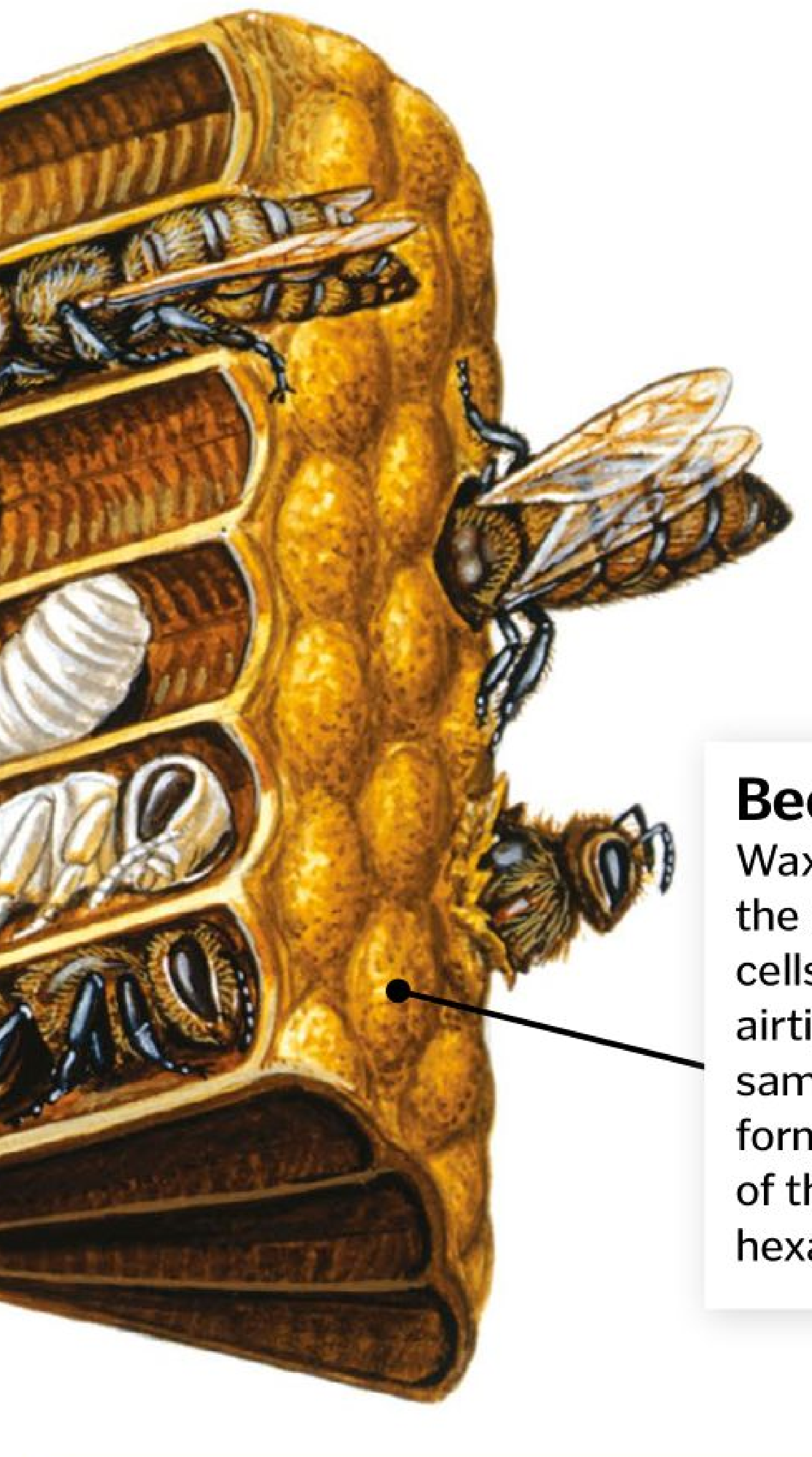


Honey cells
These cells hold the rewards of a hard day's work. An average hive can produce around 11kg of honey a year.

Waggle dance
In order to get the best nectar, bees communicate flower locations by 'waggle dancing' to indicate the direction and distance of a food source to other bees.

DID YOU KNOW? *Honeybees can fly up to 32kph while foraging for nectar but reduce their speed to about 19kph on a full stomach*





Pollen cells
Honey isn't the only food stored in hives: pollen mixed with nectar or honey is left to mature before consumption.

Brood cells
The queen will lay her eggs here. Bees develop at different rates: 24 days for drones, 21 days for worker bees and 16 days for queens.

Beeswax
Wax secreted from the bees covers the cells to keep them airtight. This is the same wax that forms the structure of the hive's hexagonal cells.

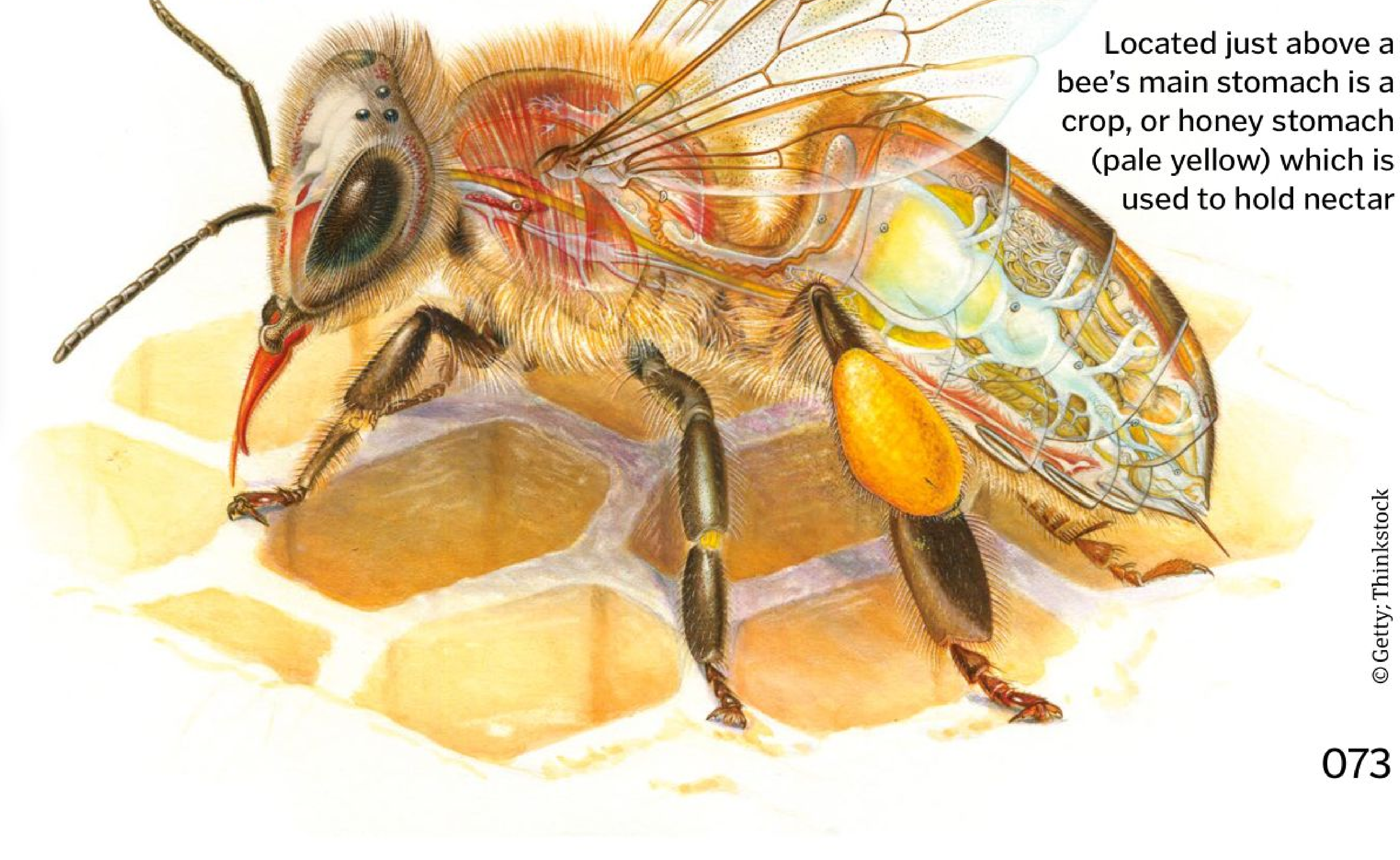
Queen bee
As head of the hive, the queen bee is continually followed around by attendants, who will feed and clean her. Her only job is to lay eggs.

Hardened honey

After a while honey may look like it's starting to go 'bad', forming sugary crystals, but in fact this is a sign of very good quality. Honey is saturated with sugars, which will naturally separate from the solution they're held in by forming crystals. This process is aided by the temperature honey is stored at.

When honey is in a cooler environment it will form these crystals – even in the hive these crystals will form when the outside temperature drops below ten degrees Celsius. Moving crystallised honey to a warmer environment will return it to its original, runny state.

Grains form in a range of sizes and quantity depending on the rate of crystallisation



Located just above a bee's main stomach is a crop, or honey stomach (pale yellow) which is used to hold nectar

© Getty; Thinkstock

Shark anatomy

Powerful swimming muscles help great white sharks to charge at prey

This streamlined fish is built for hunting. Check out the specs on this killer model

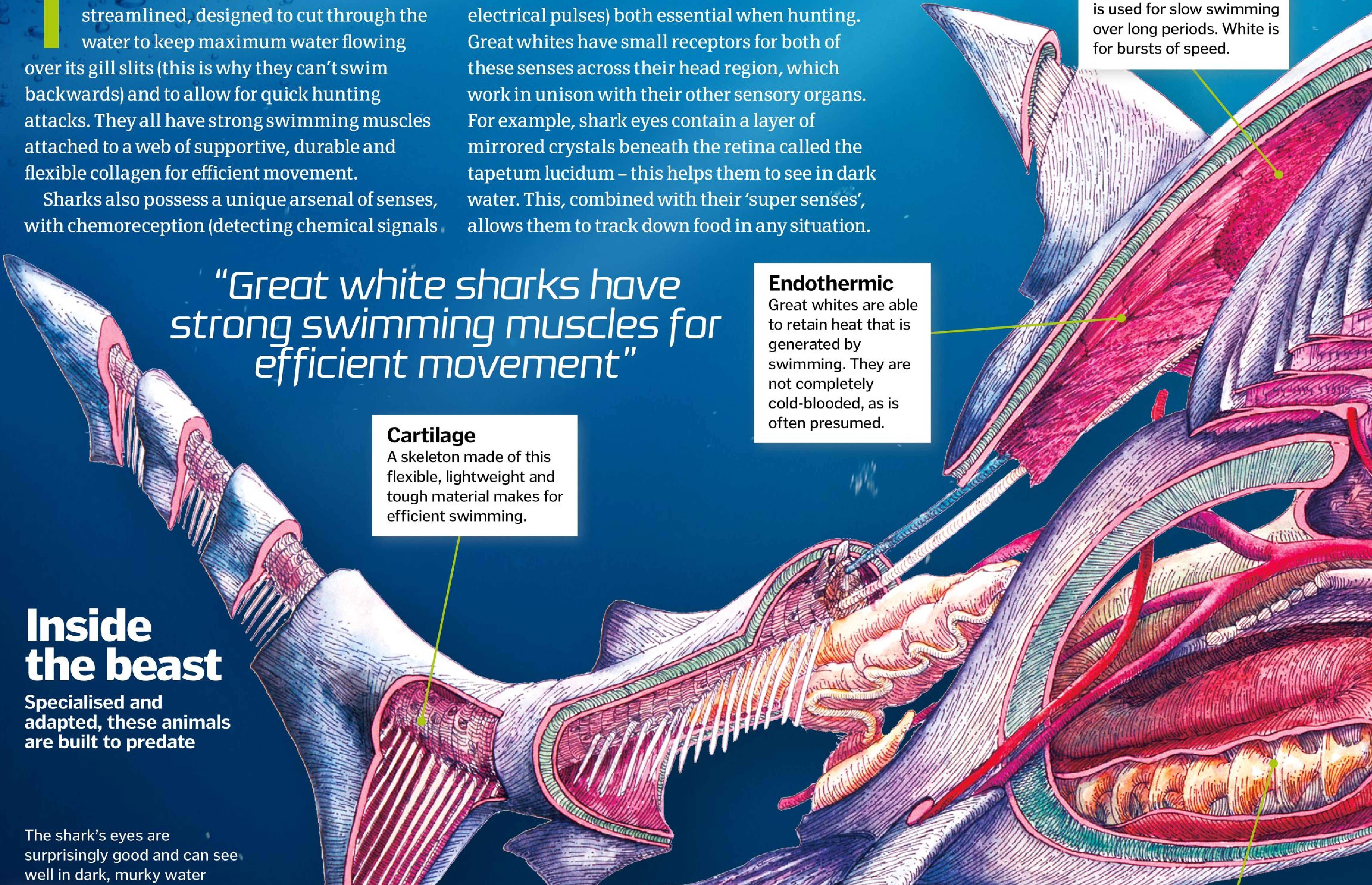
The shark's body type is slender and streamlined, designed to cut through the water to keep maximum water flowing over its gill slits (this is why they can't swim backwards) and to allow for quick hunting attacks. They all have strong swimming muscles attached to a web of supportive, durable and flexible collagen for efficient movement.

Sharks also possess a unique arsenal of senses, with chemoreception (detecting chemical signals in the water) and electroreception (detecting electrical pulses) both essential when hunting. Great whites have small receptors for both of these senses across their head region, which work in unison with their other sensory organs. For example, shark eyes contain a layer of mirrored crystals beneath the retina called the tapetum lucidum – this helps them to see in dark water. This, combined with their 'super senses', allows them to track down food in any situation.

> *"Great white sharks have strong swimming muscles for efficient movement"*

Inside the beast

Specialised and adapted, these animals are built to predate



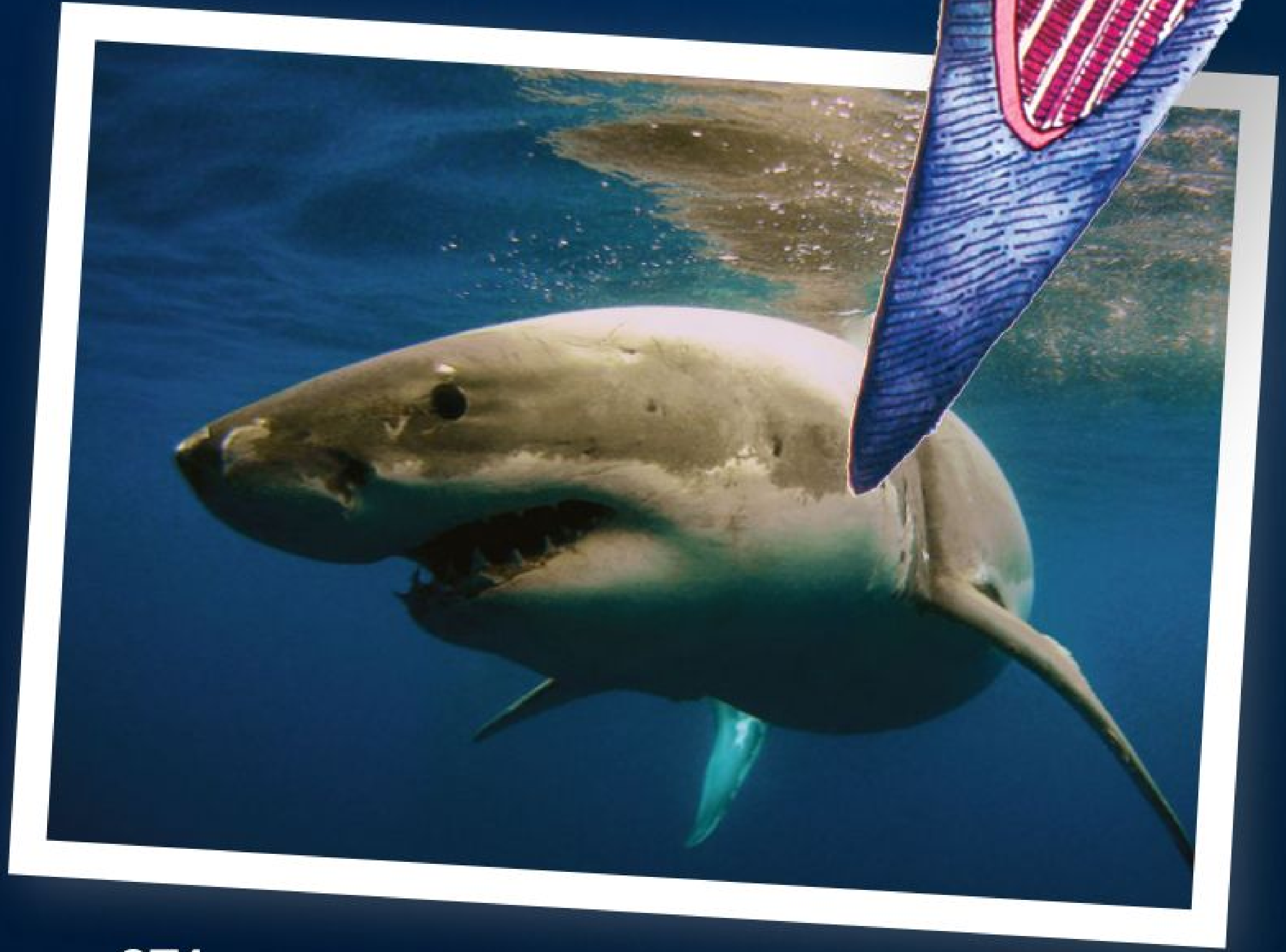
Muscular frame
There are two muscle types: red and white. Red is used for slow swimming over long periods. White is for bursts of speed.

Endothermic
Great whites are able to retain heat that is generated by swimming. They are not completely cold-blooded, as is often presumed.

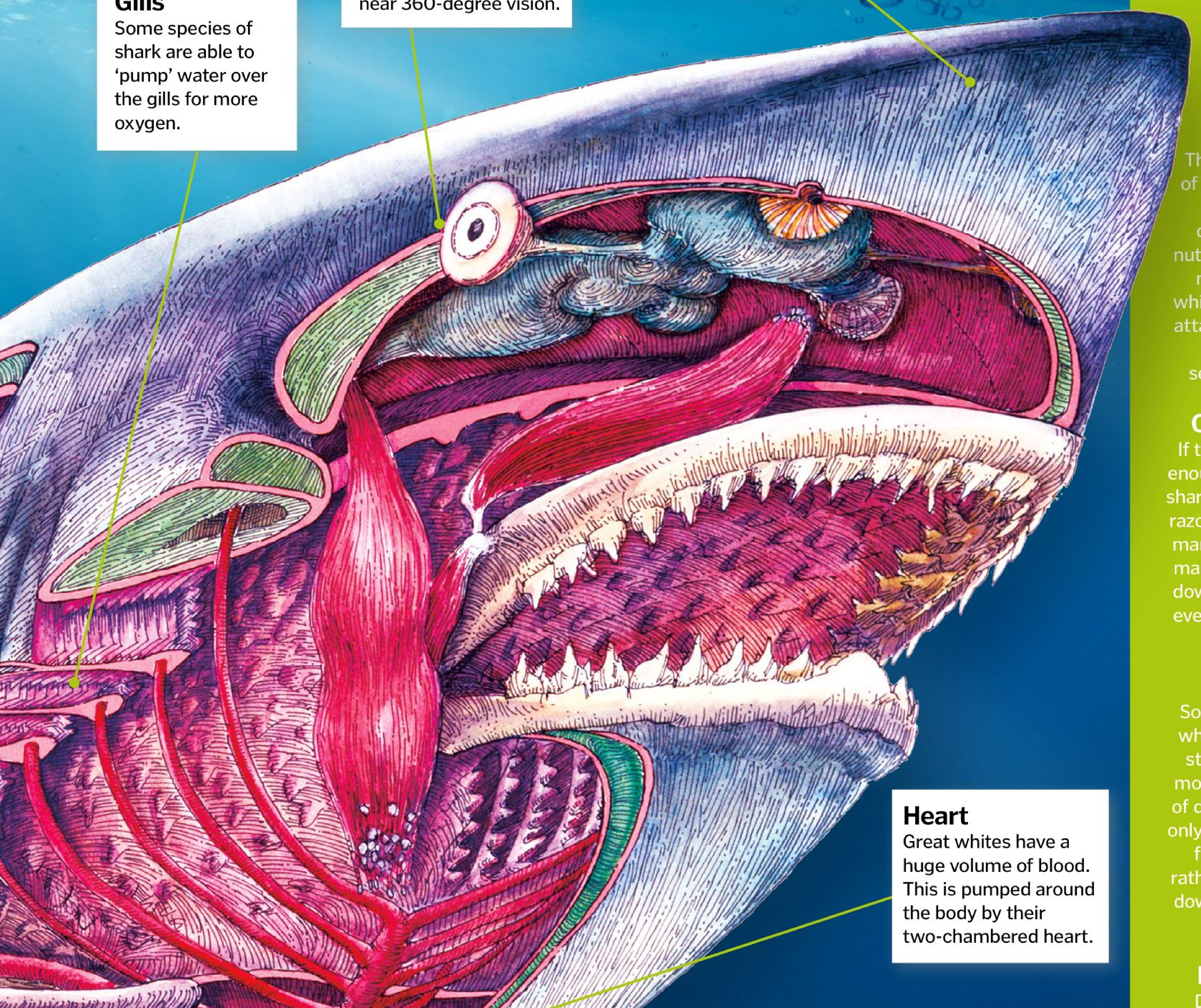
Cartilage
A skeleton made of this flexible, lightweight and tough material makes for efficient swimming.

Liver
A large, fatty liver aids buoyancy, and liver oil can provide fuel for long ocean swims.

The shark's eyes are surprisingly good and can see well in dark, murky water



All over the shark's rostrum (nose) are sensitive pores that help the great white to hunt



Gills
Some species of shark are able to 'pump' water over the gills for more oxygen.

Eyes
With eyes at either side of its head, a shark has near 360-degree vision.

Ampullae of Lorenzini
Tiny pores in the rostrum connect to nerves to detect electromagnetic pulses in the water.

Heart
Great whites have a huge volume of blood. This is pumped around the body by their two-chambered heart.

Shark menu

Great whites are known hunters, but what is the catch of the day?

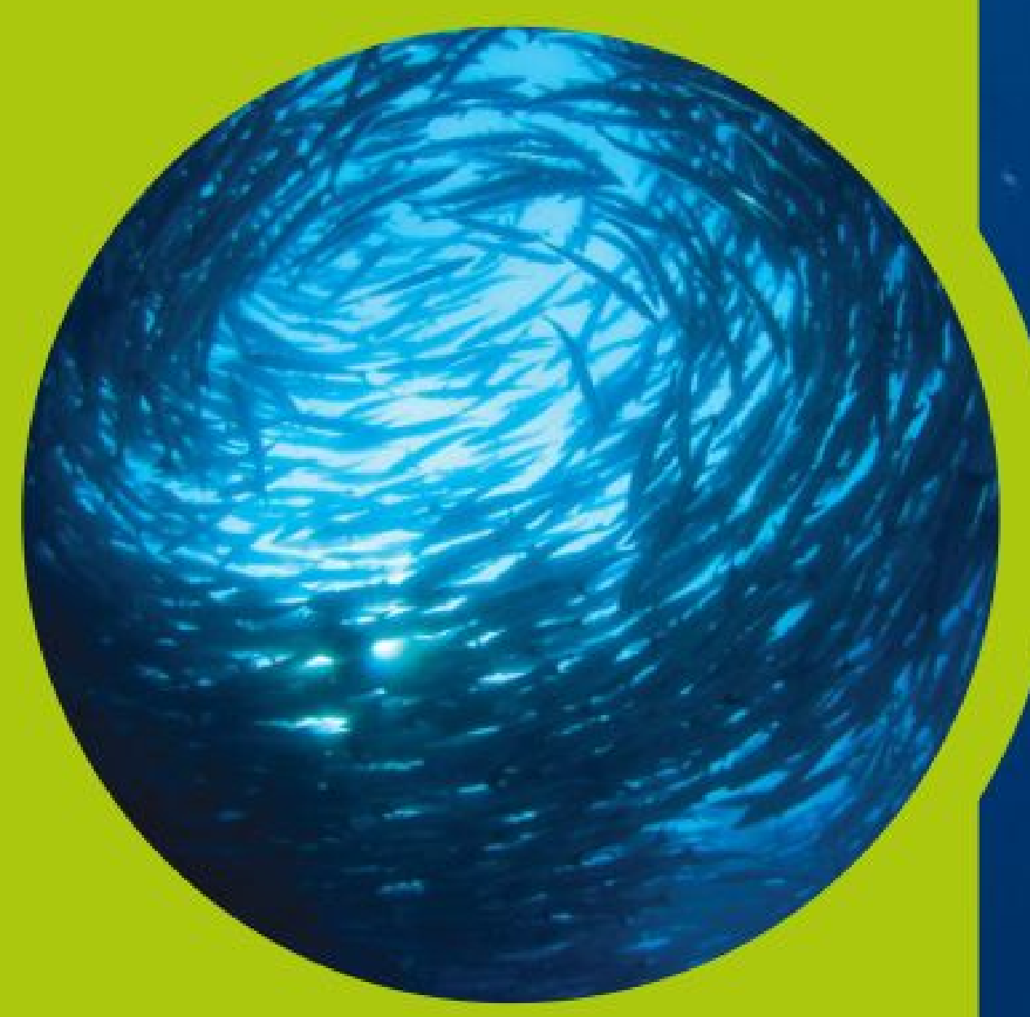
Seals

The fatty blubber of these pinnipeds makes for a delicious and nutritious meal for mature great whites. They often attack from below to catch the seal unawares.

Cetaceans

If they are hungry enough, great white sharks will turn their razor-sharp teeth to many other marine mammals, hunting down dolphins and even small whales.

Fish



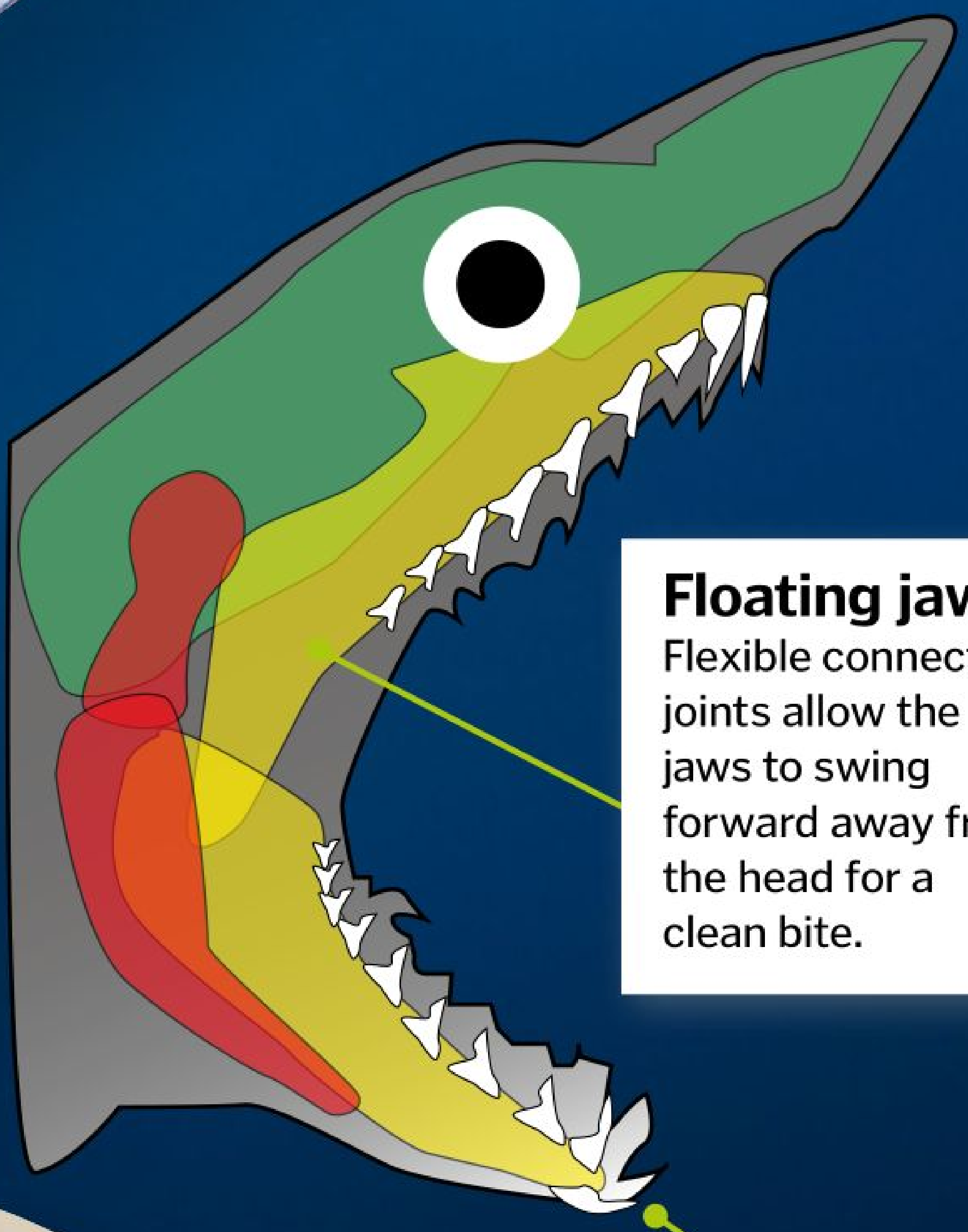
Some adult great white sharks may stick to eating a more juvenile type of diet, choosing to only feed on smaller fish and squid rather than hunting down large marine mammals.

Leftovers

Despite being skilled hunters, great whites will take a free meal. Individuals have been witnessed tucking into ocean carrion such as whale carcasses.

Great white teeth

The teeth of a great white shark are broadly triangular shaped, with serrated edges that come into play as the shark shakes its prey from side to side in order to take a bite. When tapered to an extreme point, these needle-like teeth are useful for impaling slippery prey like fish and blubbery seals.

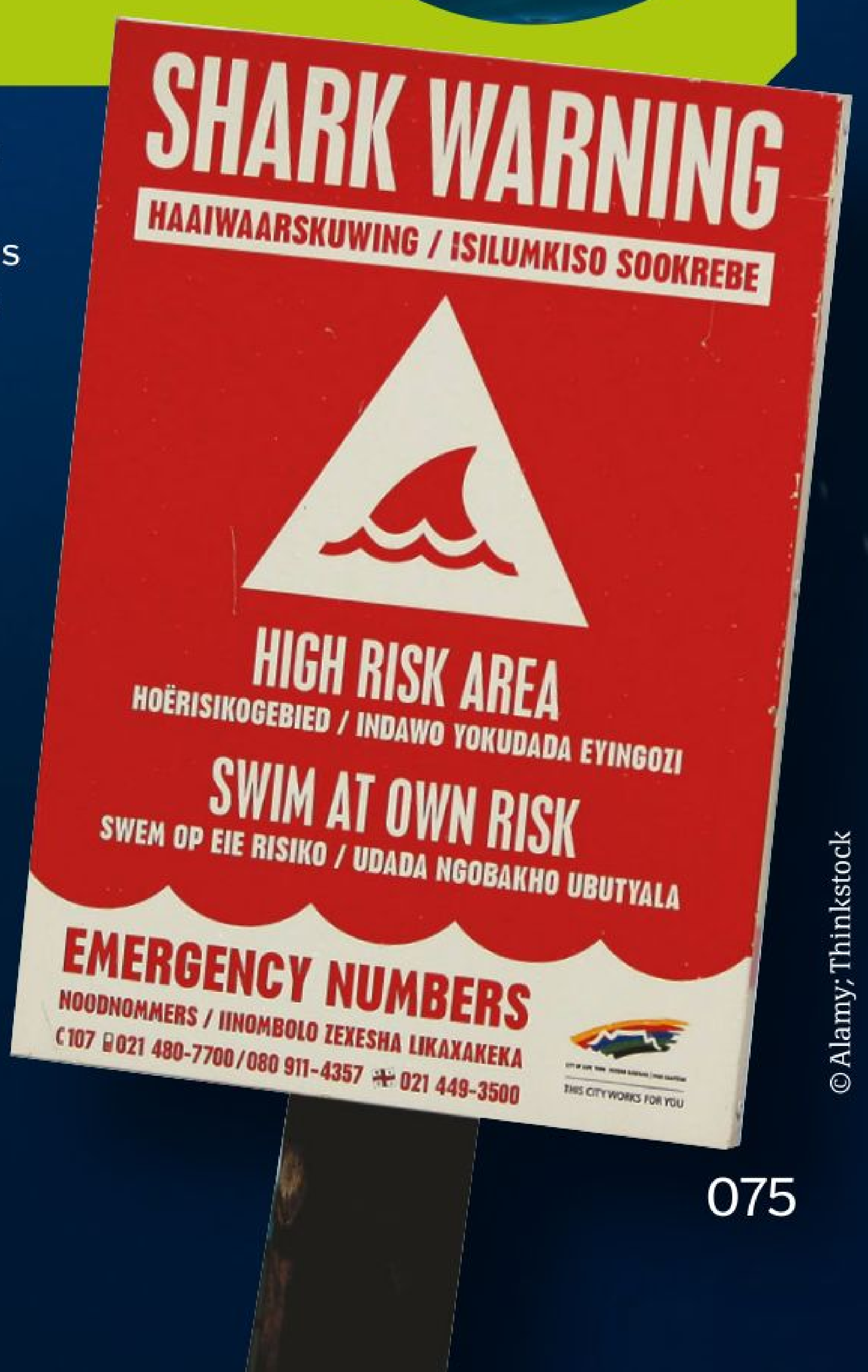


Floating jaw
Flexible connecting joints allow the jaws to swing forward away from the head for a clean bite.

Teeth
Arranged in rows, the shark's pointed and serrated teeth are continually replaced.

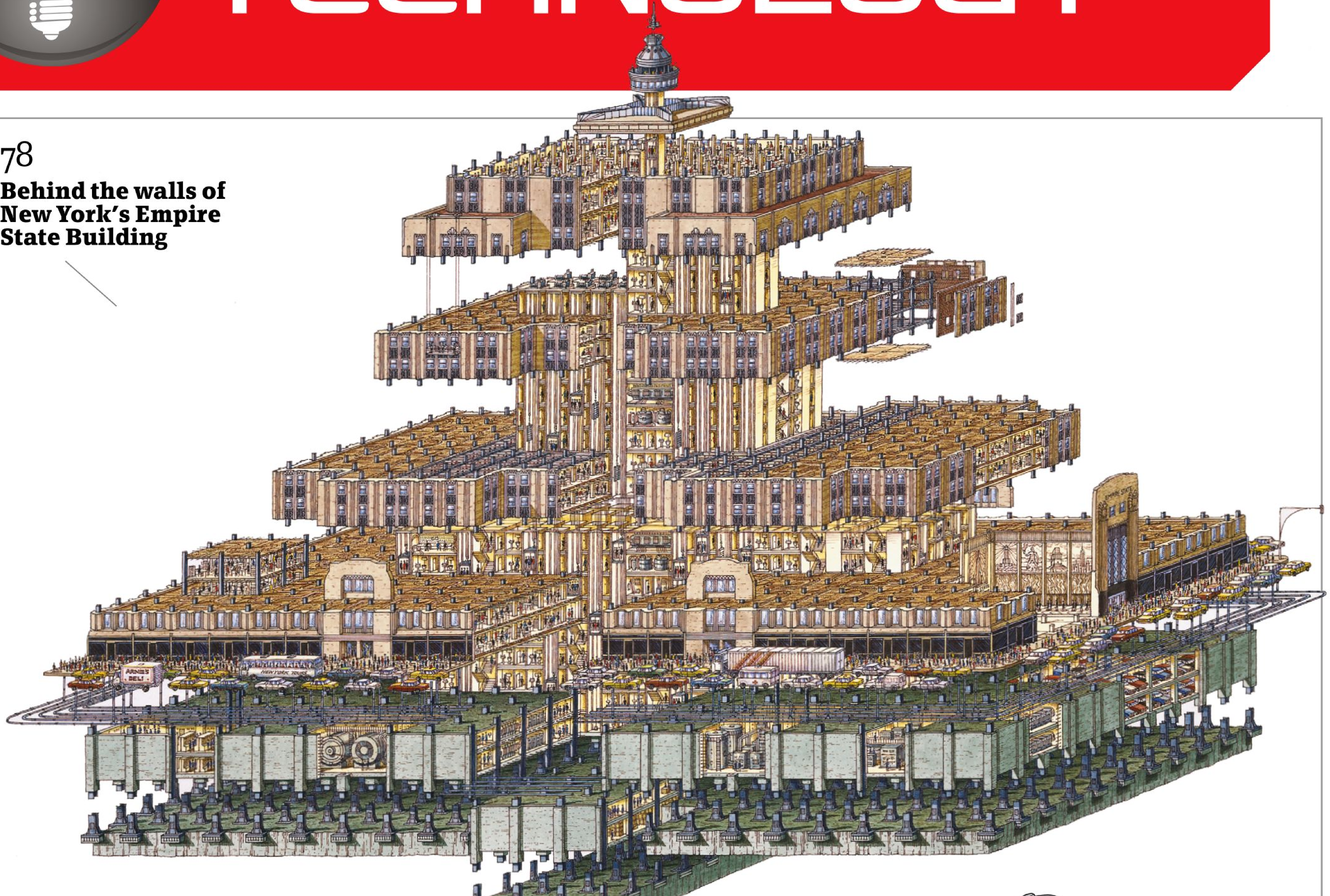
Shark teeth routinely fall out and are replaced from rows growing behind the 'working' teeth

Sharks don't hunt people – we're not as nutritious as other prey


SHARK WARNING
HAAIWAARSKUWING / ISILUMKISO SOOKREBE
HIGH RISK AREA
HOËRISIKOGEBIED / INDAWO YOKUDADA EYINGOZI
SWIM AT OWN RISK
SWEM OP EIE RISIKO / UDADA NGOBAKHO UBUTYALA
EMERGENCY NUMBERS
NOODNOMMERS / IINOMBOLO ZEXESHA LIKAXAKEKA
C107 ☎021 480-7700 / 080 911-4357 ✈ 021 449-3500
THIS CITY WORKS FOR YOU

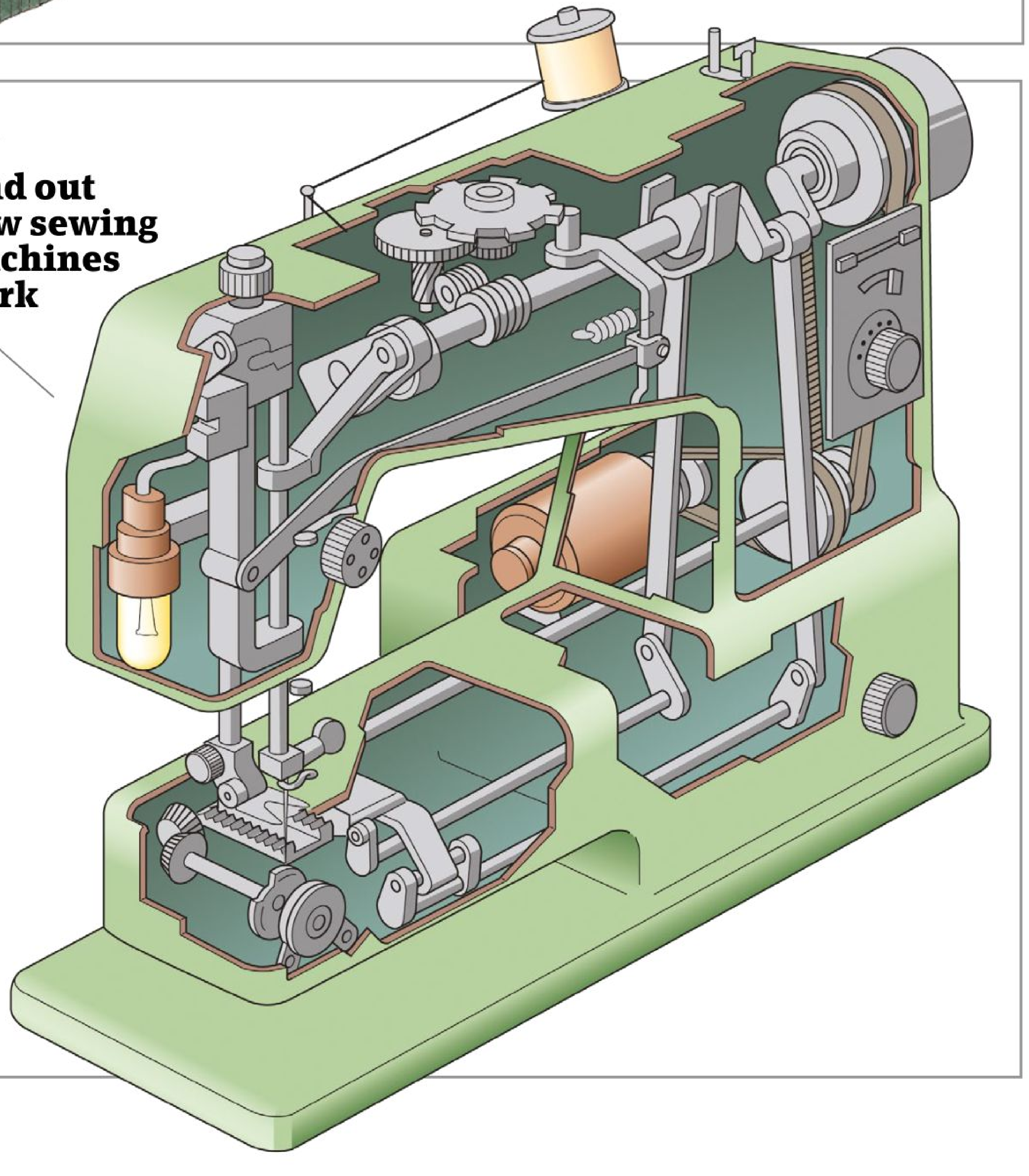
© Alamy; Thinkstock

TECHNOLOGY



78
Behind the walls of New York's Empire State Building

80
Discover the secrets of CT scanners



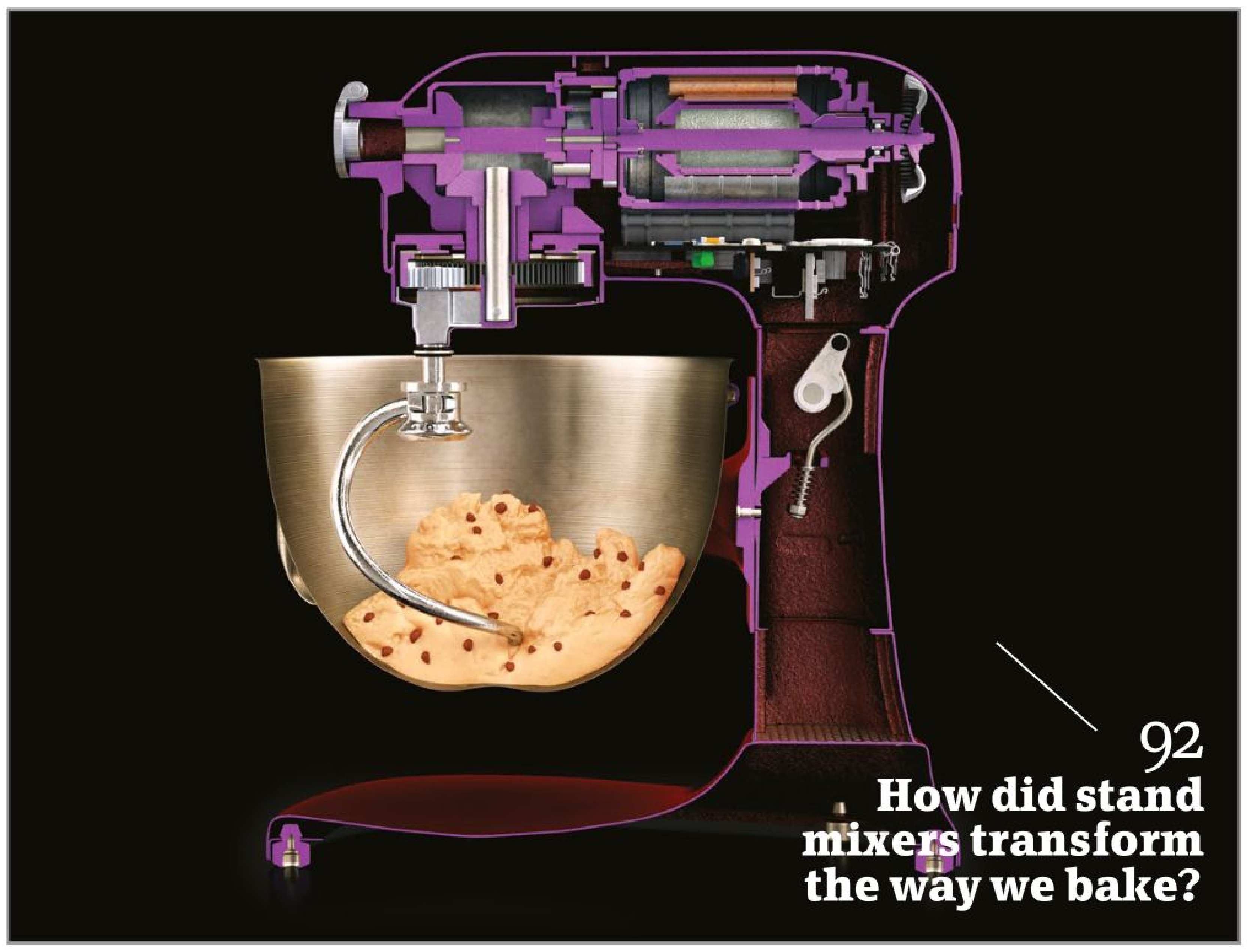
88
Find out how sewing machines work

78 The Empire State Building
80 How does a CT scanner work?
82 Explore London's super-sewer
86 Welcome to your future smart home
88 How do sewing machines work?
89 Exploring a coal mine
90 Hoover Dam construction
92 Stand mixers

Just a moment
Just a moment

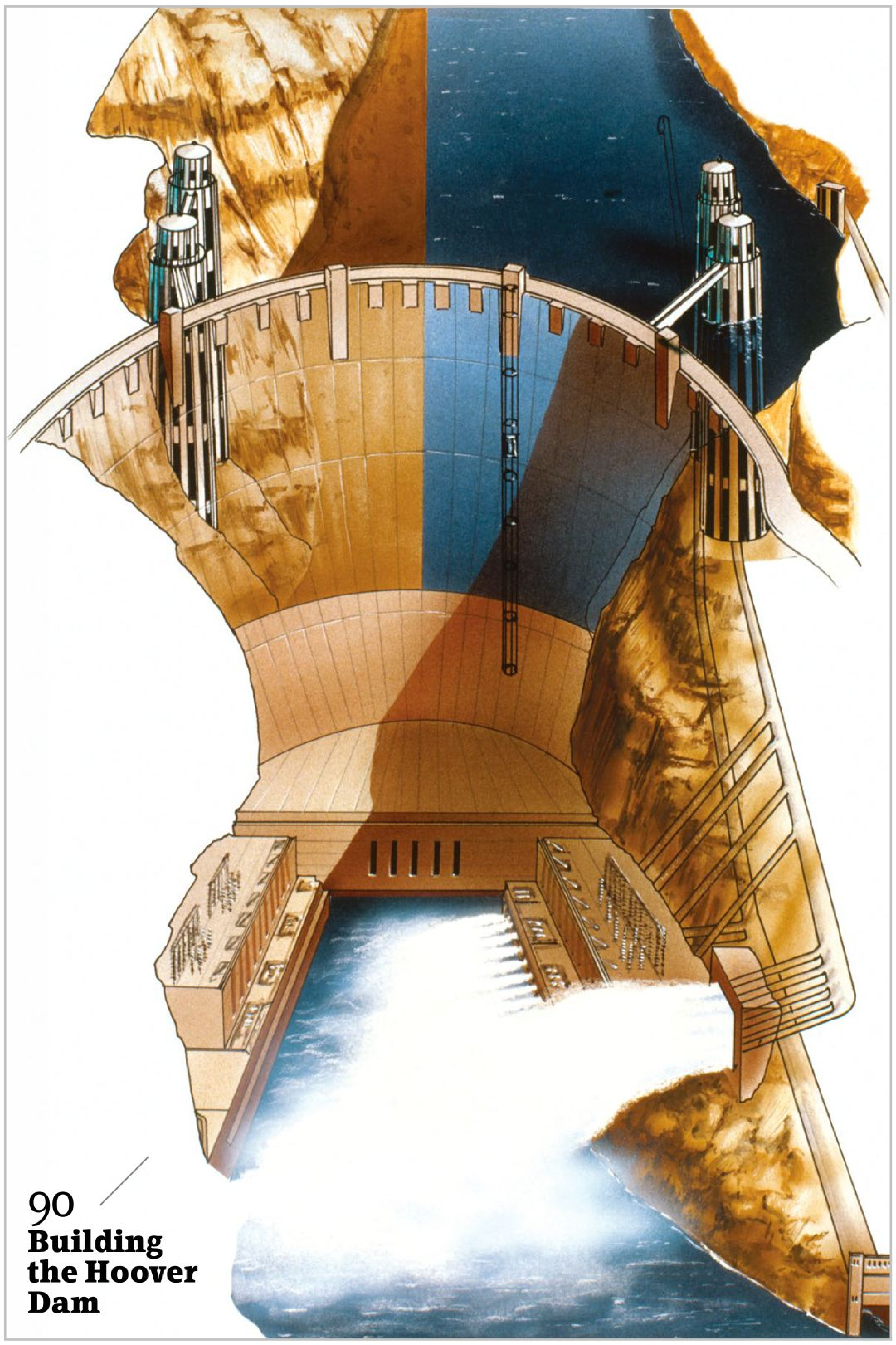
86

Discover the smart home of the future



92

How did stand mixers transform the way we bake?

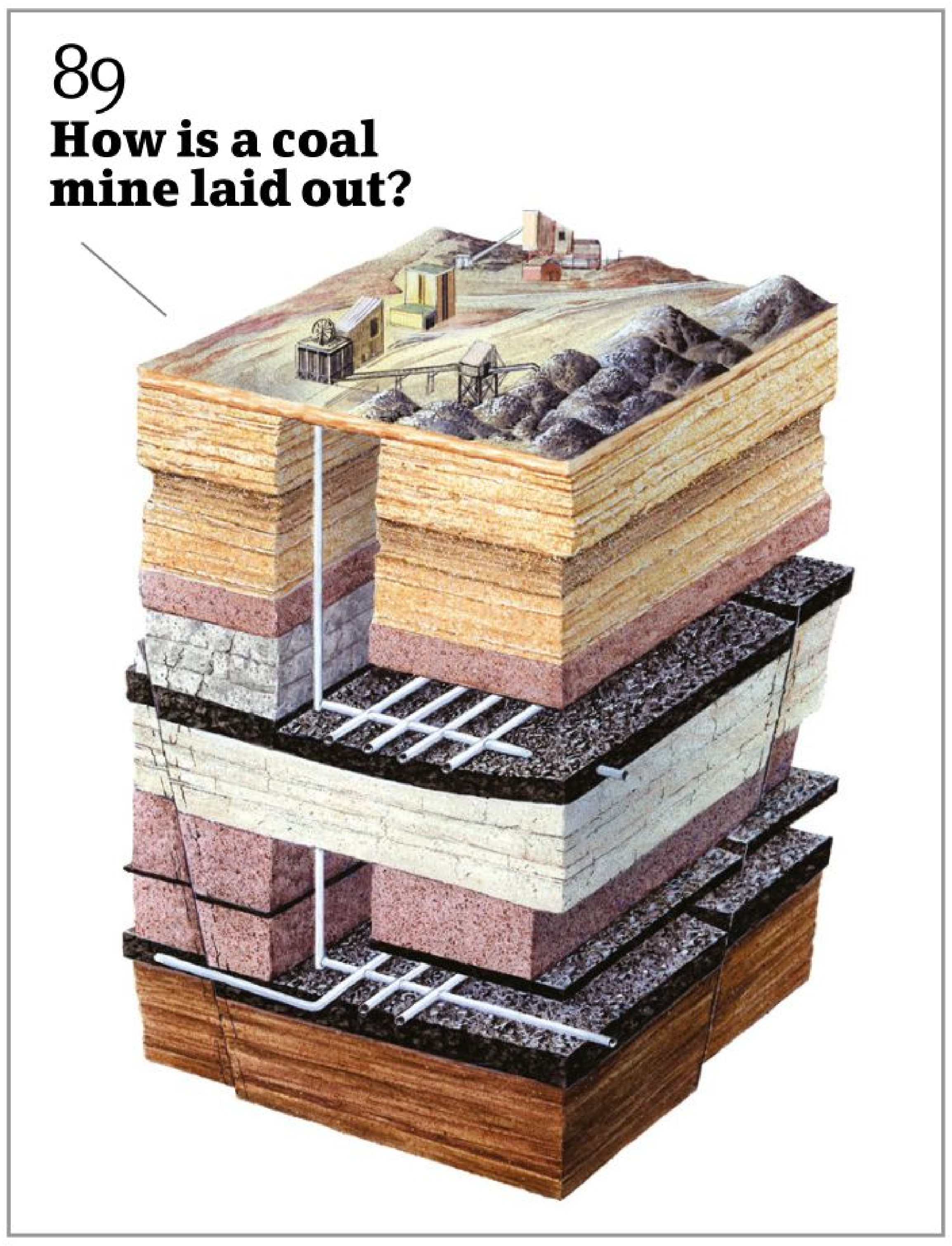


90

Building the Hoover Dam

82

Inside London's super-sewer



89

How is a coal mine laid out?

The Empire State Building

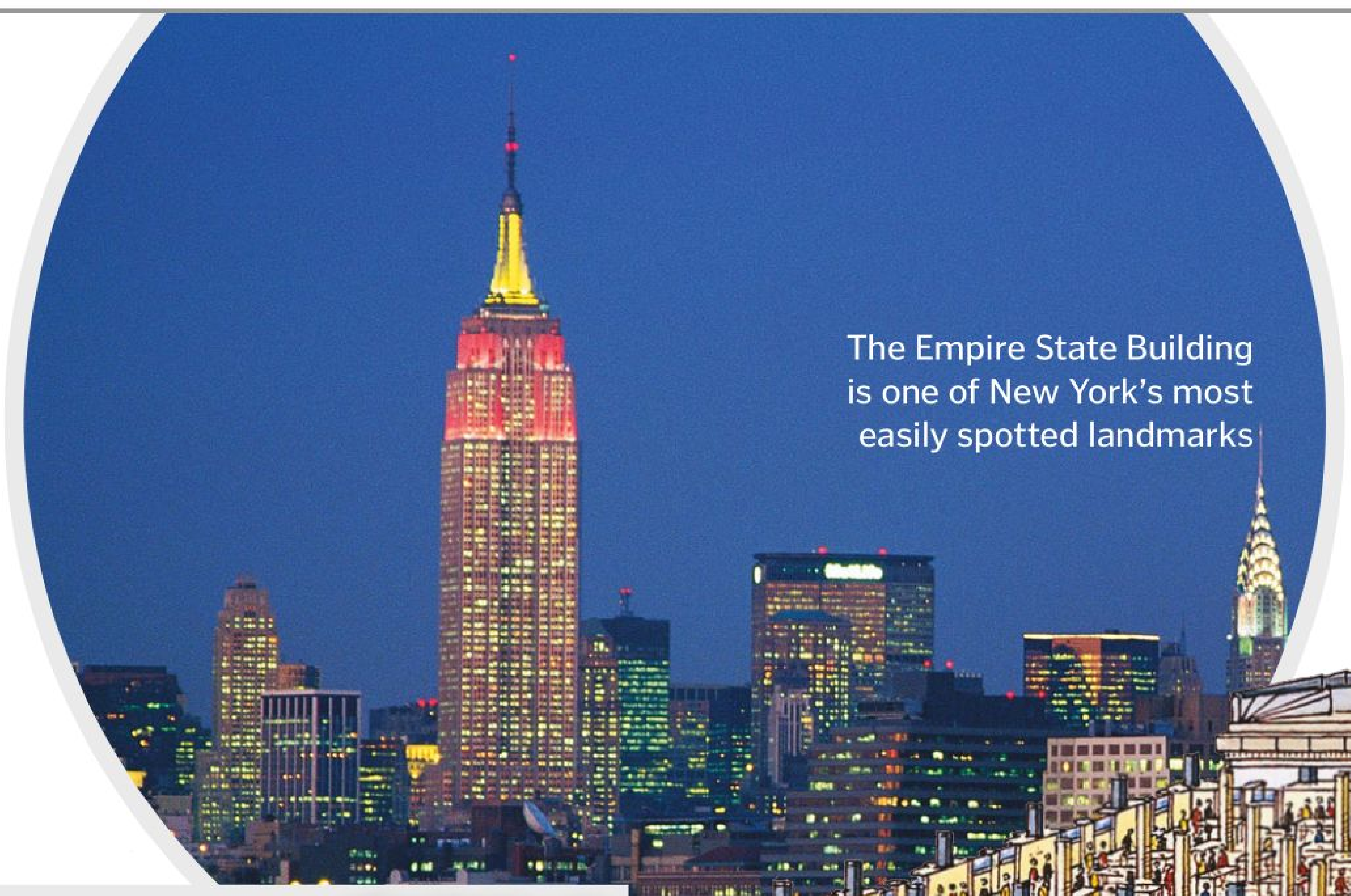
How this US icon came to tower over New York City

With 103 floors and a 56-metre (185-foot) spire, the Empire State Building is an incredible 443.2 metres (1,454 feet) high. The world's tallest skyscraper when it was opened on 1 May 1931, it pipped New York's beautiful 319-metre (1,046-foot) Chrysler Building to the record and held onto it until 1970, when New York City saw the World Trade Centre spring from the pavement. They certainly build them big in the Big Apple and for 40 years, the Empire State Building was the biggest of them all.

The invention of steel framing in the late-19th century had made it possible for buildings to be taller than ever. While brick would eventually collapse under its own weight if you piled on too many floors, a honeycomb-like frame of steel beams could take the strain and spread the pressure of the upper floors throughout the building. Another 19th-century development – the elevator – raised the limit on how many storeys you could put on a building, for the simple reason that you can't expect someone to walk up 102 flights of stairs.

Construction began in March 1930. Financed by two former General Motors executives, John J Raskob and Pierre S du Pont, they applied the same revolutionary style of working that they'd used in the factory, with assembly lines of men putting the building together in shifts. However, without the benefit of modern cranes and lifting equipment, materials were hoisted up by pulleys and moved around the inside of the building on narrow railway tracks.

As many as 3,500 workers were on the building at once, many of them (known as 'sky boys') balancing on beams high above the city with no harnesses or helmets. It would be considered incredibly dangerous and reckless today, but those conditions were accepted as part of the job in 1930. After all, only five people died in the 410 days of its construction…

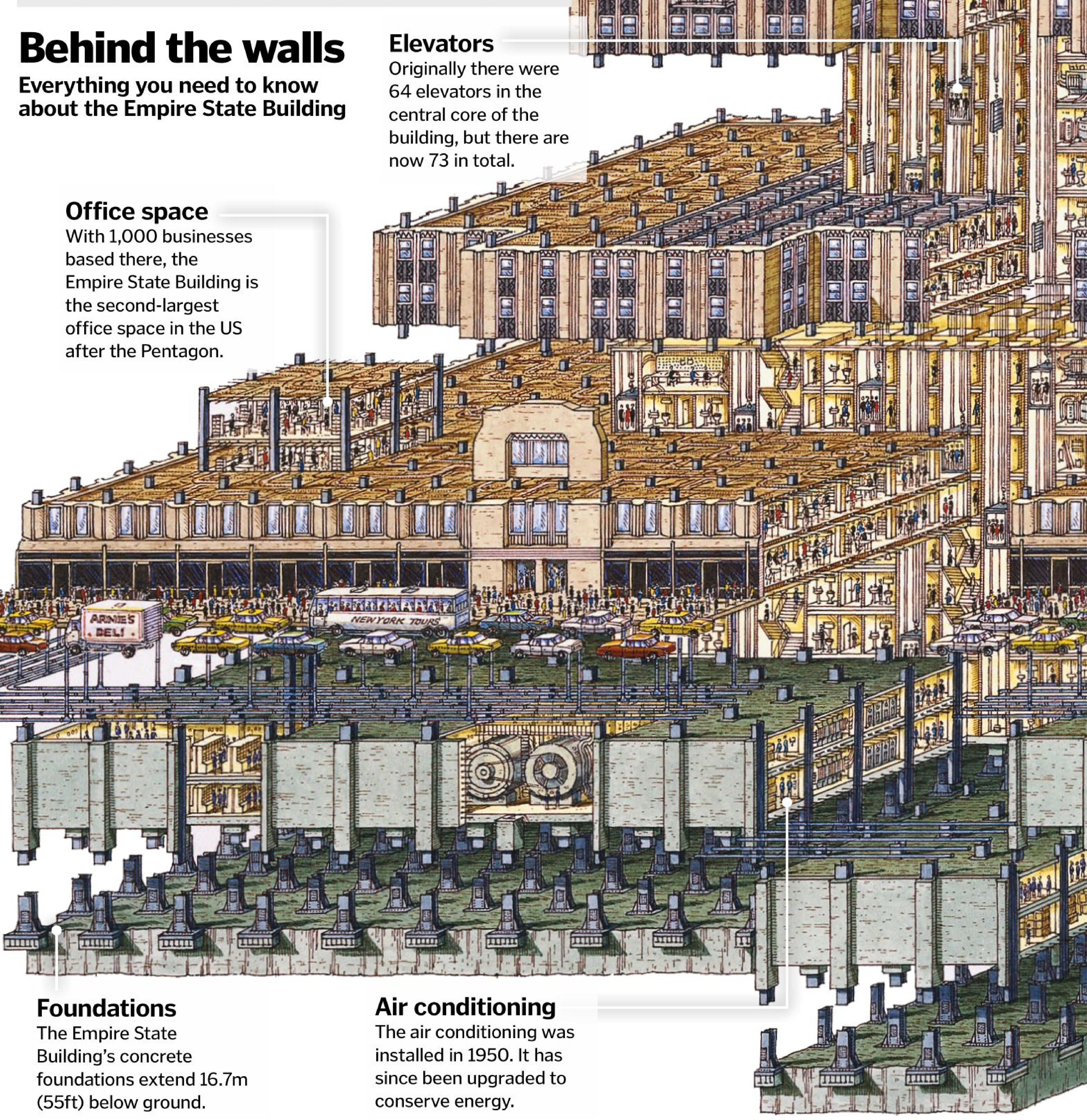


The Empire State Building is one of New York's most easily spotted landmarks

The 'sky boys' put their lives on the line

Behind the walls

Everything you need to know about the Empire State Building



Elevators
Originally there were 64 elevators in the central core of the building, but there are now 73 in total.

Office space
With 1,000 businesses based there, the Empire State Building is the second-largest office space in the US after the Pentagon.

Foundations
The Empire State Building's concrete foundations extend 16.7m (55ft) below ground.

Air conditioning
The air conditioning was installed in 1950. It has since been upgraded to conserve energy.

STRANGE BUT TRUE

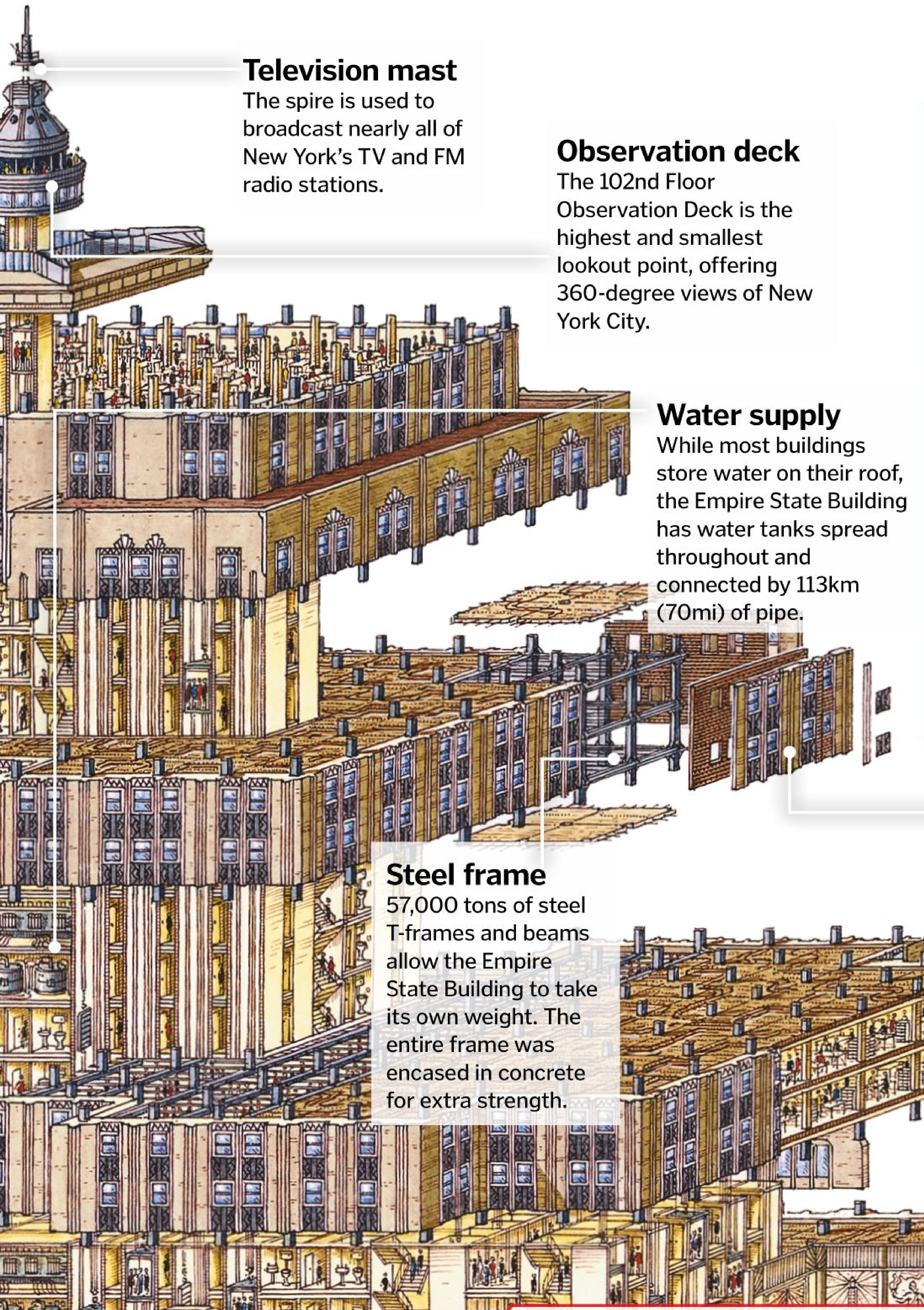
TALL AMBITIONS

What was the Empire State's spire built for?

A Signalling UFOs **B** Flagpole **C** Mooring airships

Answer:
The Empire State Building's spire was originally intended for anchoring airships. The updrafts of wind caused by the sheer size of the building meant it was too dangerous to be actually used for this purpose.

DID YOU KNOW? *The Empire State owns the longest survived elevator fall after Betty Lou Oliver plummeted 75 storeys in 1945*



Television mast
The spire is used to broadcast nearly all of New York's TV and FM radio stations.

Observation deck
The 102nd Floor Observation Deck is the highest and smallest lookout point, offering 360-degree views of New York City.

Water supply
While most buildings store water on their roof, the Empire State Building has water tanks spread throughout and connected by 113km (70mi) of pipe.

Steel frame
57,000 tons of steel T-frames and beams allow the Empire State Building to take its own weight. The entire frame was encased in concrete for extra strength.

Limestone panels
The outside of the skyscraper is covered in panels of Indiana Limestone, behind them are 10 million bricks.

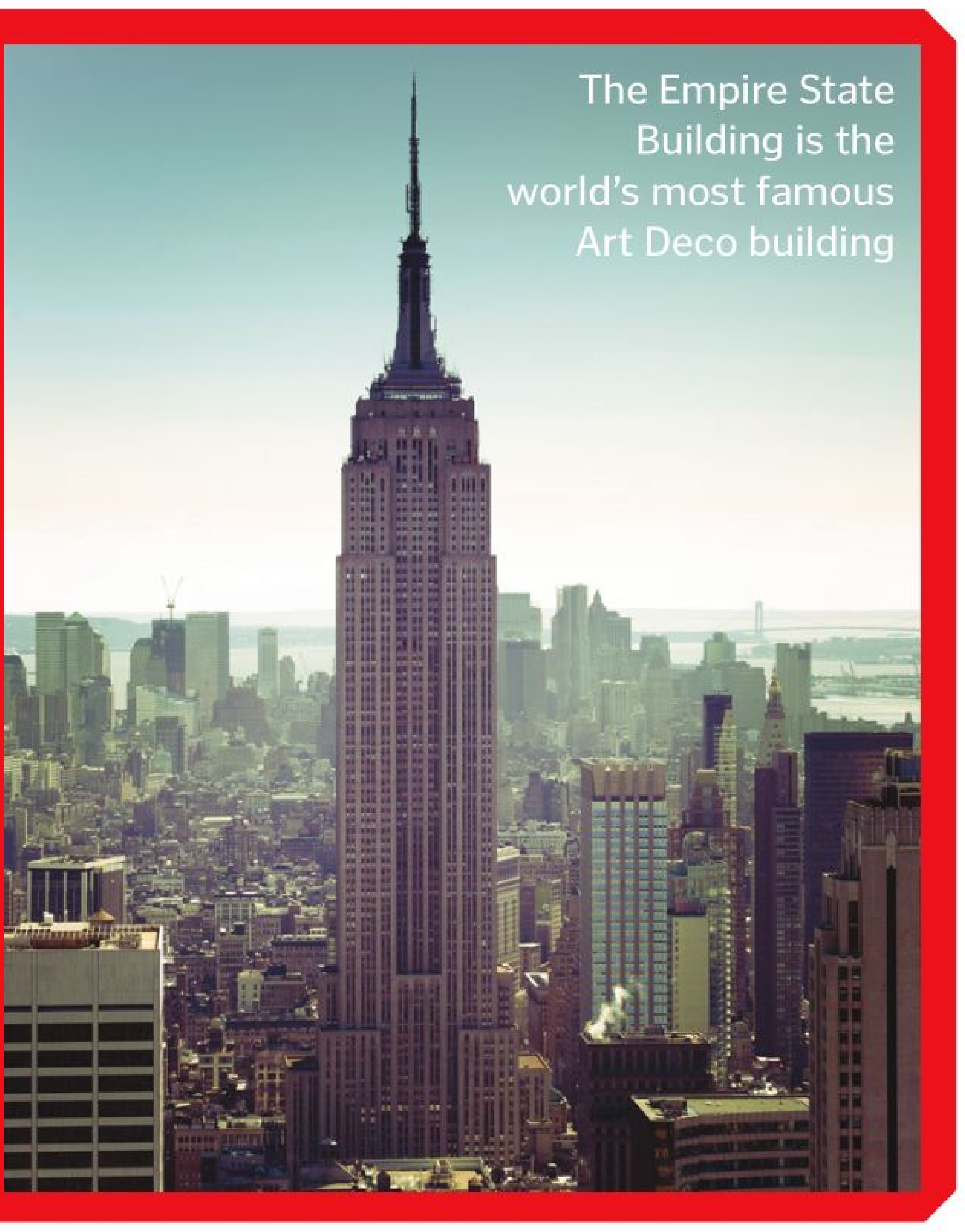
Windows
Did you know there are 6,500 windows in the Empire State Building? That's a lot of cleaning!

Entrance
The main entrance has a 9.1m (30ft) high frontage with diamond-shaped frames of glass and two carved eagles on pillars.

Beautiful shapes

Although not as stylish as the Chrysler Building, the Empire State is an example of the architectural style known as Art Deco. Prominent in the 1920s, 1930s and 1940s, Art Deco is recognised by its bold geometric shapes, symmetrical design and ornate decorations.

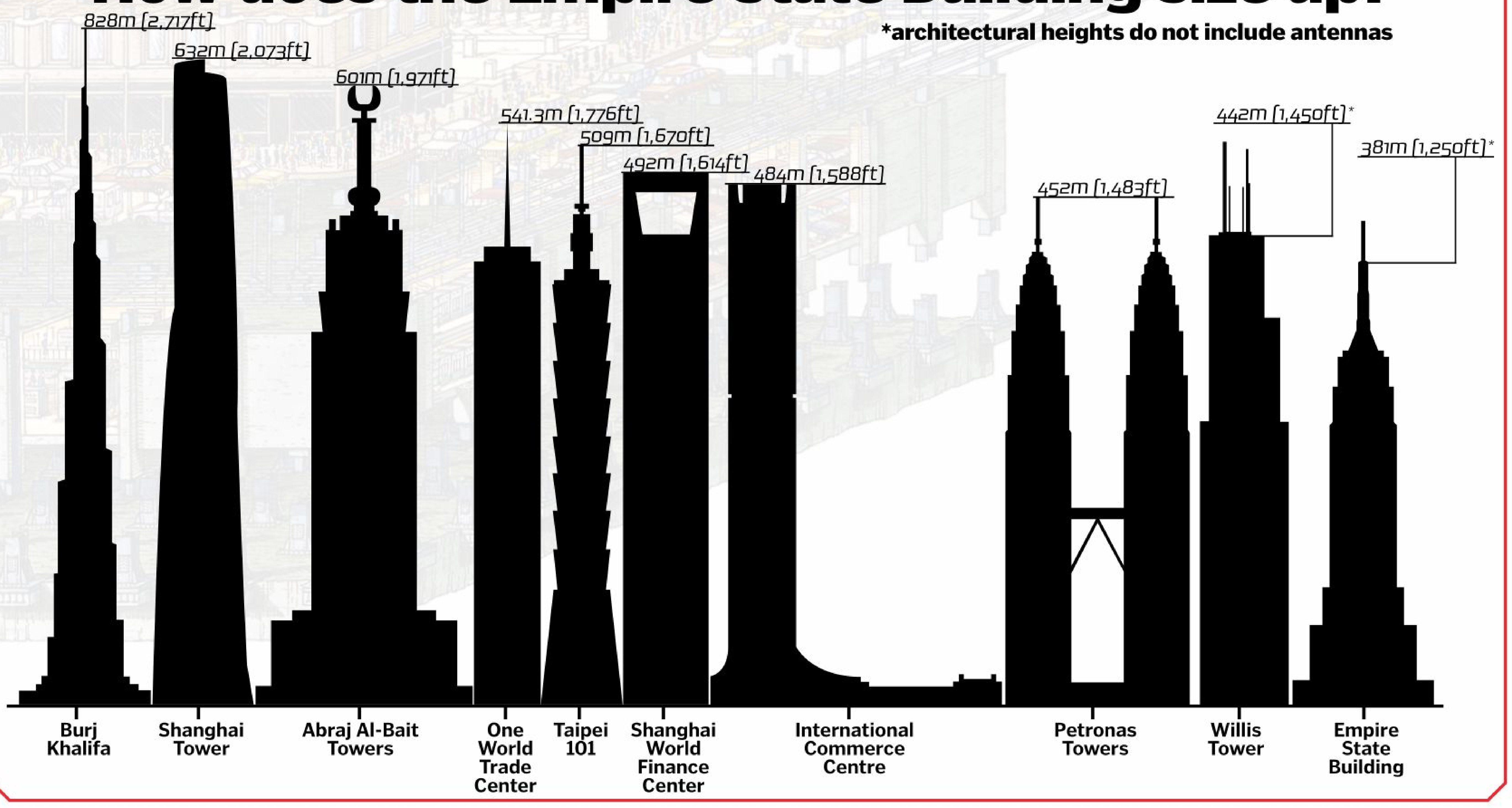
The Empire State Building's most prominent Art Deco features are the 'setbacks', where levels of the building become narrower the higher it goes, with overlaps between the small parts and larger parts. Because they look like steps, they're also called 'stepbacks' and give the Empire State its instantly recognisable shape. Angular sculptures can be found over the entrances, but its inside was where the decorations were at their most impressive with a gold-leaf mural on the lobby ceiling, marble walls and floors, and Art Deco chandeliers.



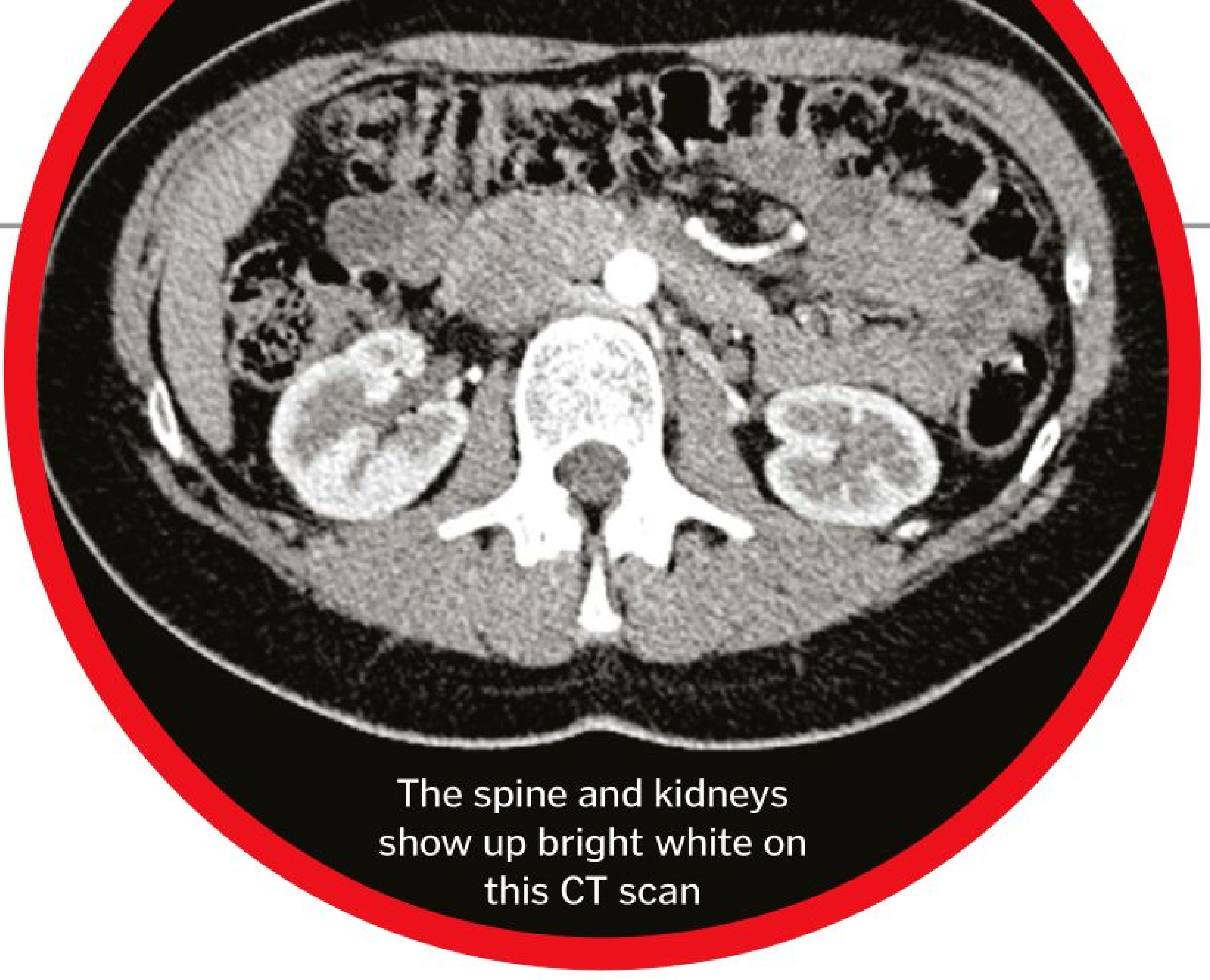
The Empire State Building is the world's most famous Art Deco building

How does the Empire State Building size up?

*architectural heights do not include antennas



© Thinkstock; DK



The spine and kidneys show up bright white on this CT scan

How does a CT scanner work?

These 3D X-rays can create detailed pictures of the inside of your body

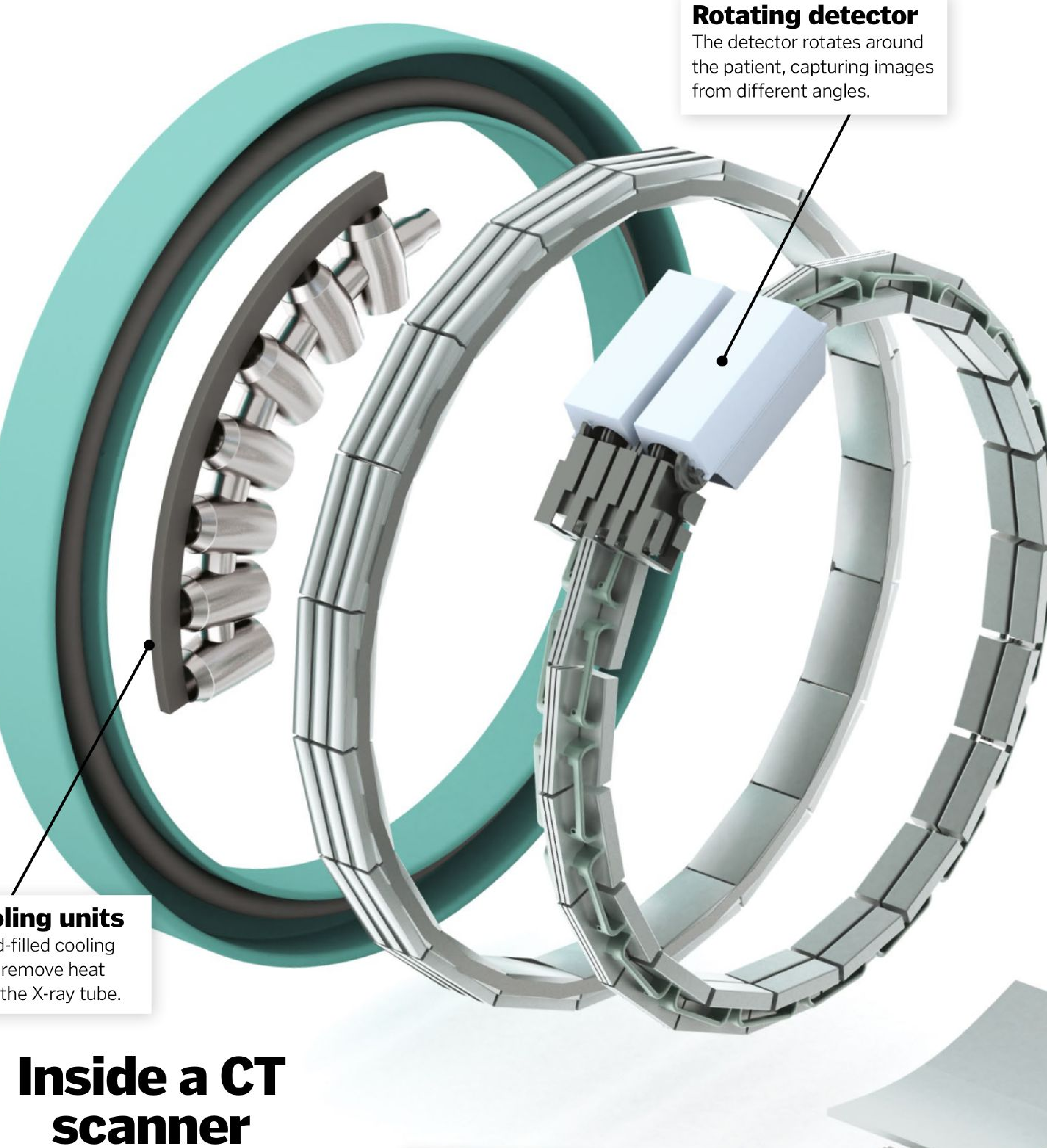
At the end of the 19th century, Wilhelm Röntgen discovered X-rays and changed medicine forever. As X-rays pass through the body, different tissues absorb different amounts of energy, leaving shadows on photographic film. For the first time, doctors could see inside their patients without having to cut them open. But the story didn't stop there.

If you capture one X-ray image you see a snapshot of the body, but with the organs piled on top of one another it's hard to make out what's going on. In 1972, Godfrey Hounsfield found a solution when he invented computerised tomography (CT) scans, thereby revolutionising medicine again.

CT scanners use a rotating ring to take X-ray images from all angles. A computer then combines these images to separate out the signals from different bones, organs and blood vessels. This creates image slices between one and ten millimetres thick, showing the inside of the body in cross-section. During the scan, a table slides the patient through the ring, capturing more and more image slices. Then the computer stacks them together to make 3D pictures of the internal organs.

The result is a much higher-resolution picture of the inside of the body. The outlines of the tissues are clearer than a normal X-ray, and the 3D shapes allow medical professionals to see abnormalities. X-ray-absorbing chemicals called contrast agents can make the pictures even clearer. For example, iodine injected into the blood can reveal the outline of the blood vessels, showing up clots. Barium swallowed in a meal or drink can highlight the outline of the digestive system, revealing tumours.

Though X-rays do deliver small amounts of ionising radiation, which can damage cells, the benefits far outweigh the risks.



Rotating detector
The detector rotates around the patient, capturing images from different angles.

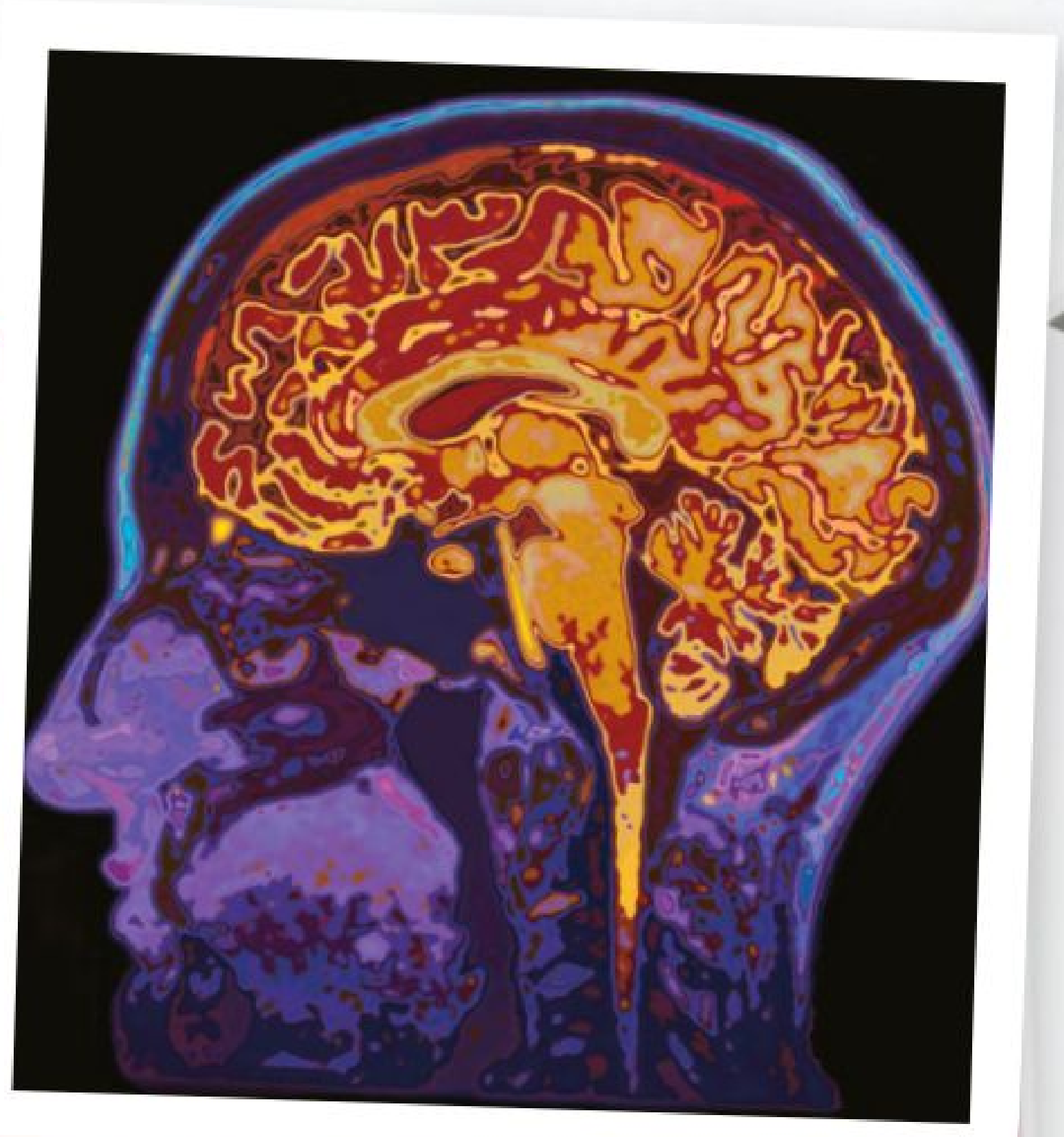
Cooling units
Liquid-filled cooling units remove heat from the X-ray tube.

Inside a CT scanner

Patients slide through a rotating ring stuffed with X-ray technology

CT vs MRI

CT scans are good for showing up bones, blood vessels and organs, but they can't capture the fine detail of soft tissues. To do this we need Magnetic Resonance Imaging (MRI). These scans use a combination of radio waves and powerful magnets to make 3D pictures. The magnets pull on the hydrogen atoms in the water molecules inside the body, rotating them so they all point in the same direction. Radio waves then knock them temporarily out of line; when they snap back in line they release energy. Detectors pick this energy up, creating a picture of where the water molecules are. Different tissues contain different amounts of water, giving a clearer view of the internal organs.



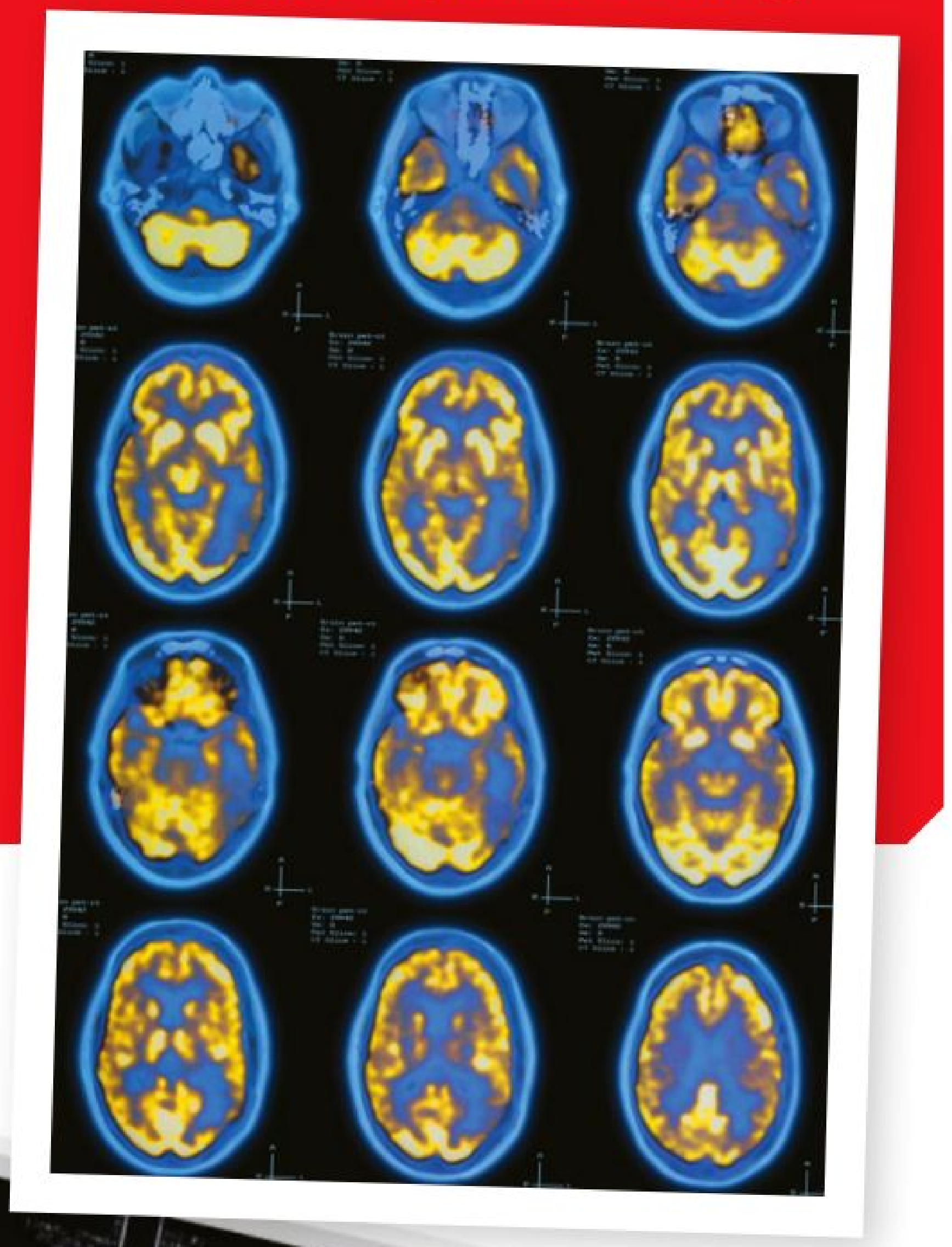
MRI scans offer a higher-resolution picture of the body's soft tissues

PET and SPECT

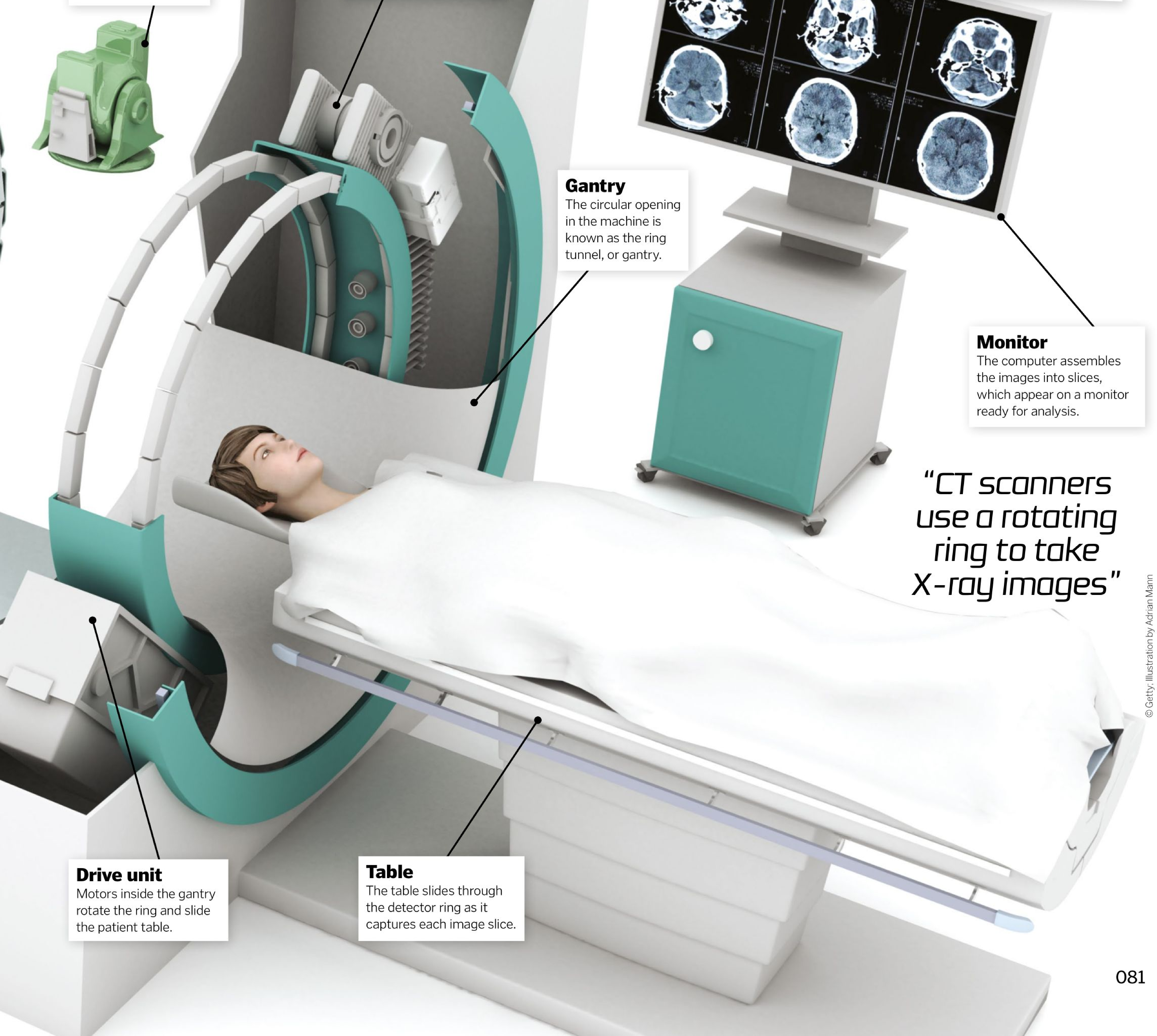
Doctors can zone in on specific parts of the body using nuclear medicine. This involves injecting, inhaling or swallowing small amounts of radioactive material to light up different tissues.

Doctors sometimes need to highlight the blood vessels to look for circulation problems. To do this they can use Single Photon Emission Computed Tomography (SPECT) scans. Patients receive an injection containing radioactive atoms, which enter the blood and release gamma rays as they circulate. When a gamma camera detects the rays, it reveals the outline of the blood vessels.

Another option is a Positron Emission Tomography, or PET scan. These use radioactive tracers that produce positrons instead of gamma rays. Positrons interact with electrons inside the body, sending bursts of energy to the detectors. PET tracers attached to sugar molecules can light up tissues using lots of energy, like active areas of the brain or growing tumours.



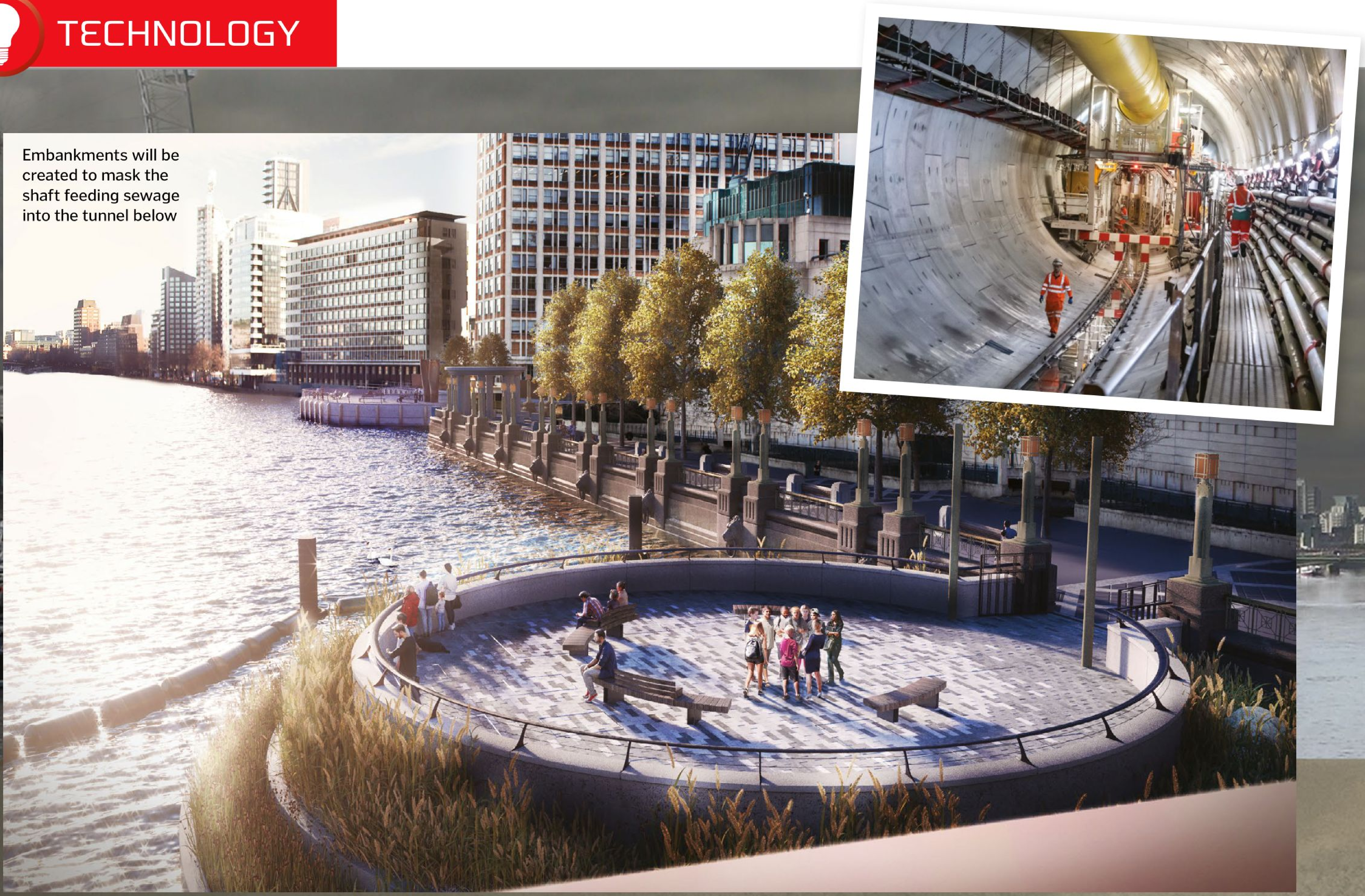
The yellow areas of the brain on this PET scan are using the most energy



X-ray source
Different tissues absorb different amounts of energy as X-rays pass through.
Fan
A fan pumps warm air out of the gantry, keeping the equipment cool.
Gantry
The circular opening in the machine is known as the ring tunnel, or gantry.
Monitor
The computer assembles the images into slices, which appear on a monitor ready for analysis.
Drive unit
Motors inside the gantry rotate the ring and slide the patient table.
Table
The table slides through the detector ring as it captures each image slice.

> *"CT scanners use a rotating ring to take X-ray images"*

© Getty; Illustration by Adrian Mann



Embankments will be created to mask the shaft feeding sewage into the tunnel below

Explore London's super-sewer

Discover the tunnel being built deep beneath the Thames River and how it's going to prevent poo from contaminating the water

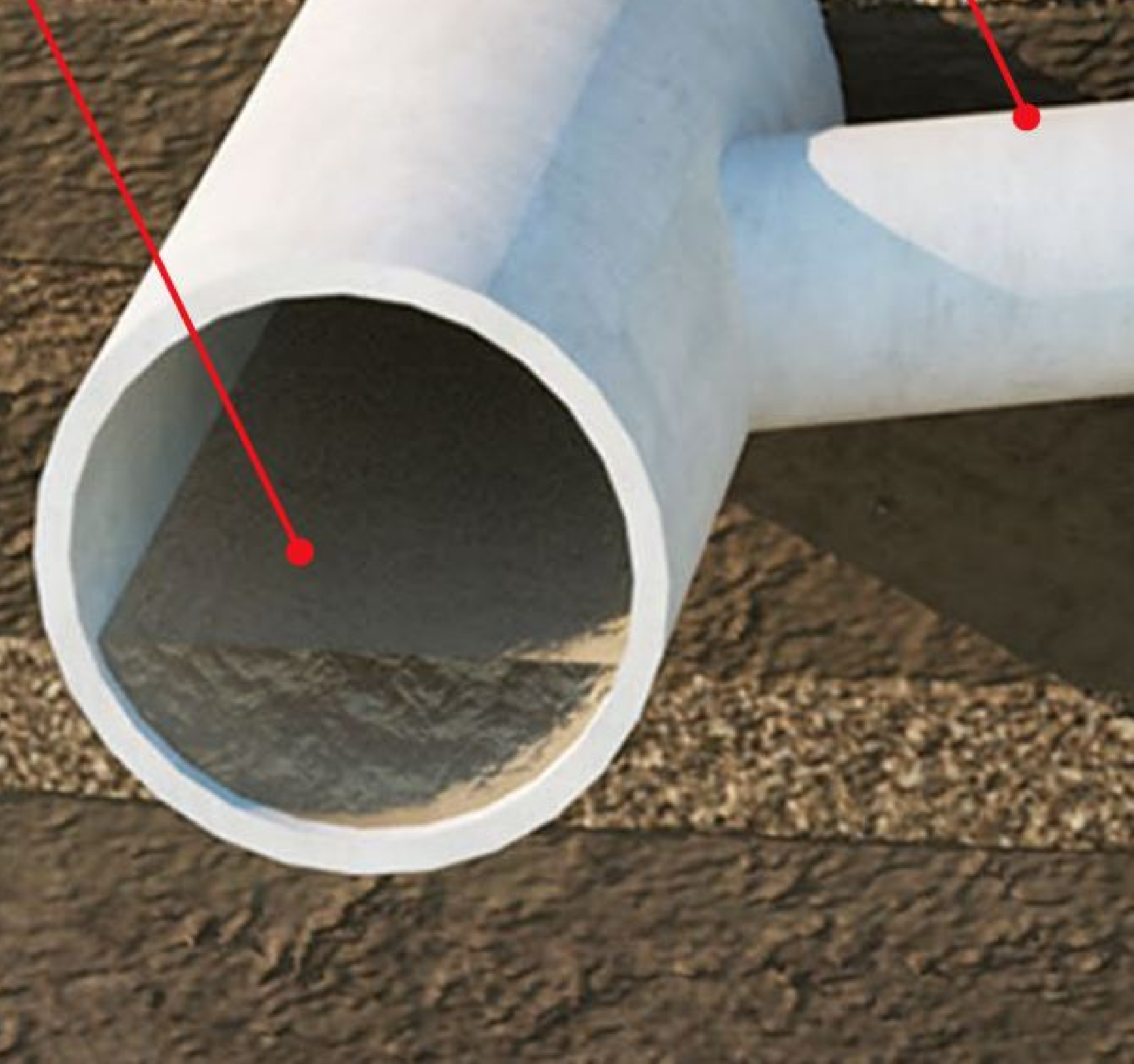
Words by **Scott Dutfield**

In the mid 1800s, London's Victorian sewer system was built to combat the growing outbreaks of cholera and typhoid fever that were killing thousands of Londoners. It was designed by chief engineer Joseph Bazalgette, used around 318 million bricks and spanned the entire city.

Although the Bazalgette sewer system has served the residents of London well over the past 150 years, it hasn't been without issues. Originally built to support the waste of 4 million people, the capital city is now home to over 8 million people and rising, putting pressure on the city's sewers. Currently the sewers are contending with 1.25 million tonnes of human waste each day.

As a fail-safe to prevent sewage from spilling onto the streets of London, the current network of pipes is connected to several overspill pipes that deposit waste into the water of the Thames. As London's population continues to grow, millions of tons of waste contaminate the river's water.

It is this overspill design that has prompted Tideway, an engineering company, to create the Thames Tideway Tunnel. As an improved



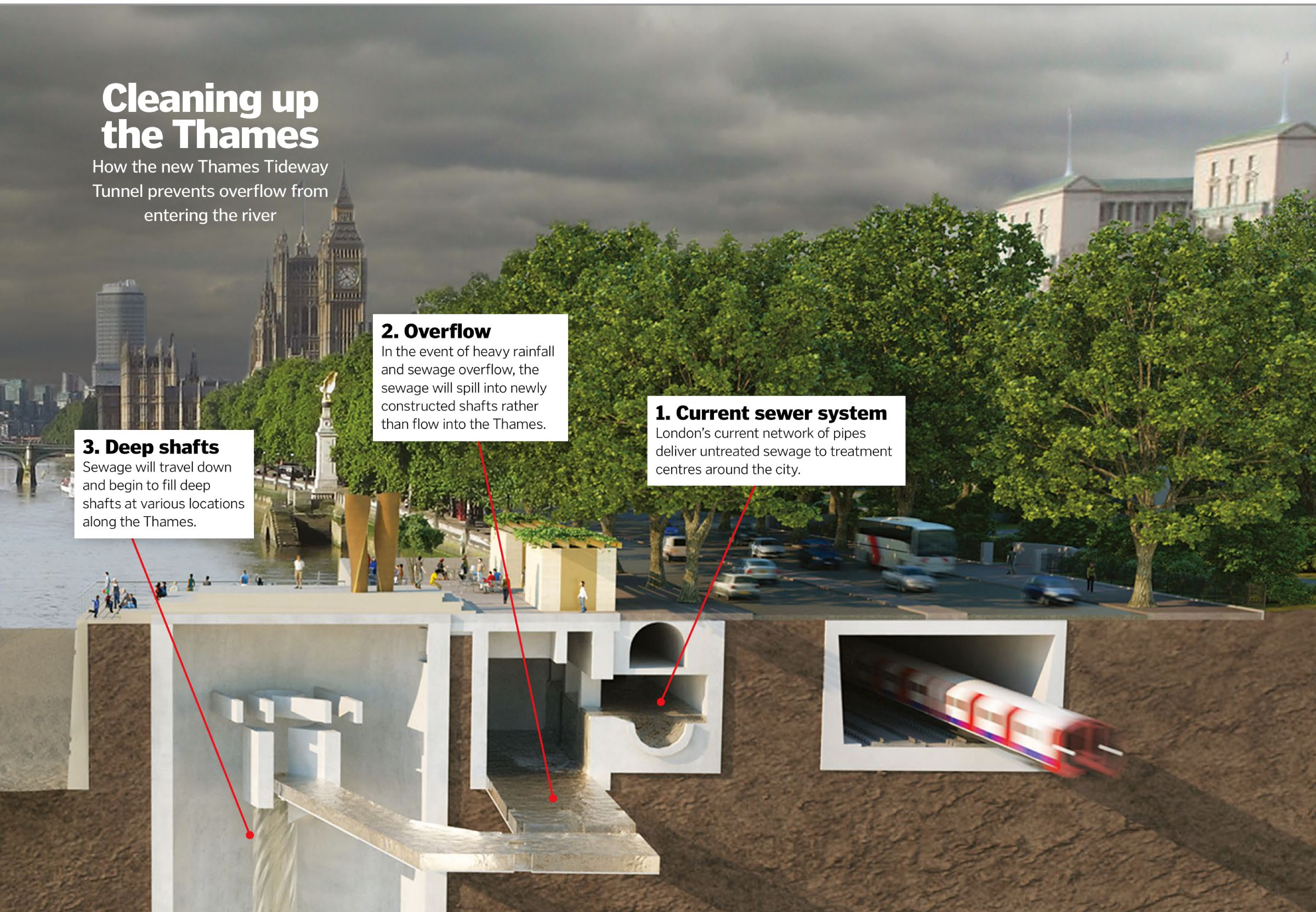
4. Sewer connections
As sewage begins to fill the shaft, it will feed via connecting pipes to the central Thames tunnel.

5. To the pumps
Collected sewage will travel beneath the Thames until it reaches Abbey Mills Pumping Station downstream.

DID YOU KNOW? *Bazalgette's original sewer network cost £6.5 million, equivalent to £250 million today*

Cleaning up the Thames

How the new Thames Tideway Tunnel prevents overflow from entering the river



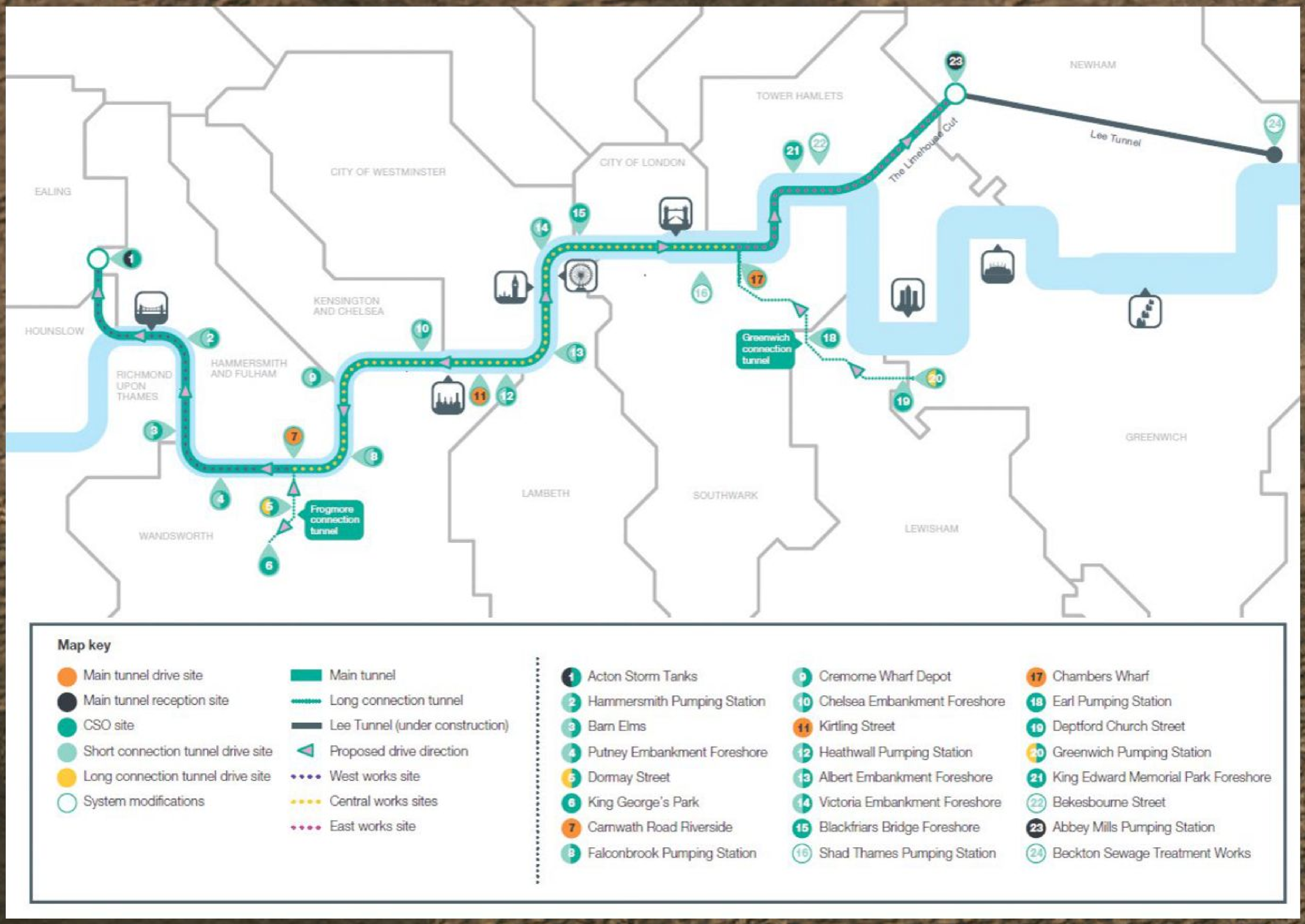
1. Current sewer system
London's current network of pipes deliver untreated sewage to treatment centres around the city.

2. Overflow
In the event of heavy rainfall and sewage overflow, the sewage will spill into newly constructed shafts rather than flow into the Thames.

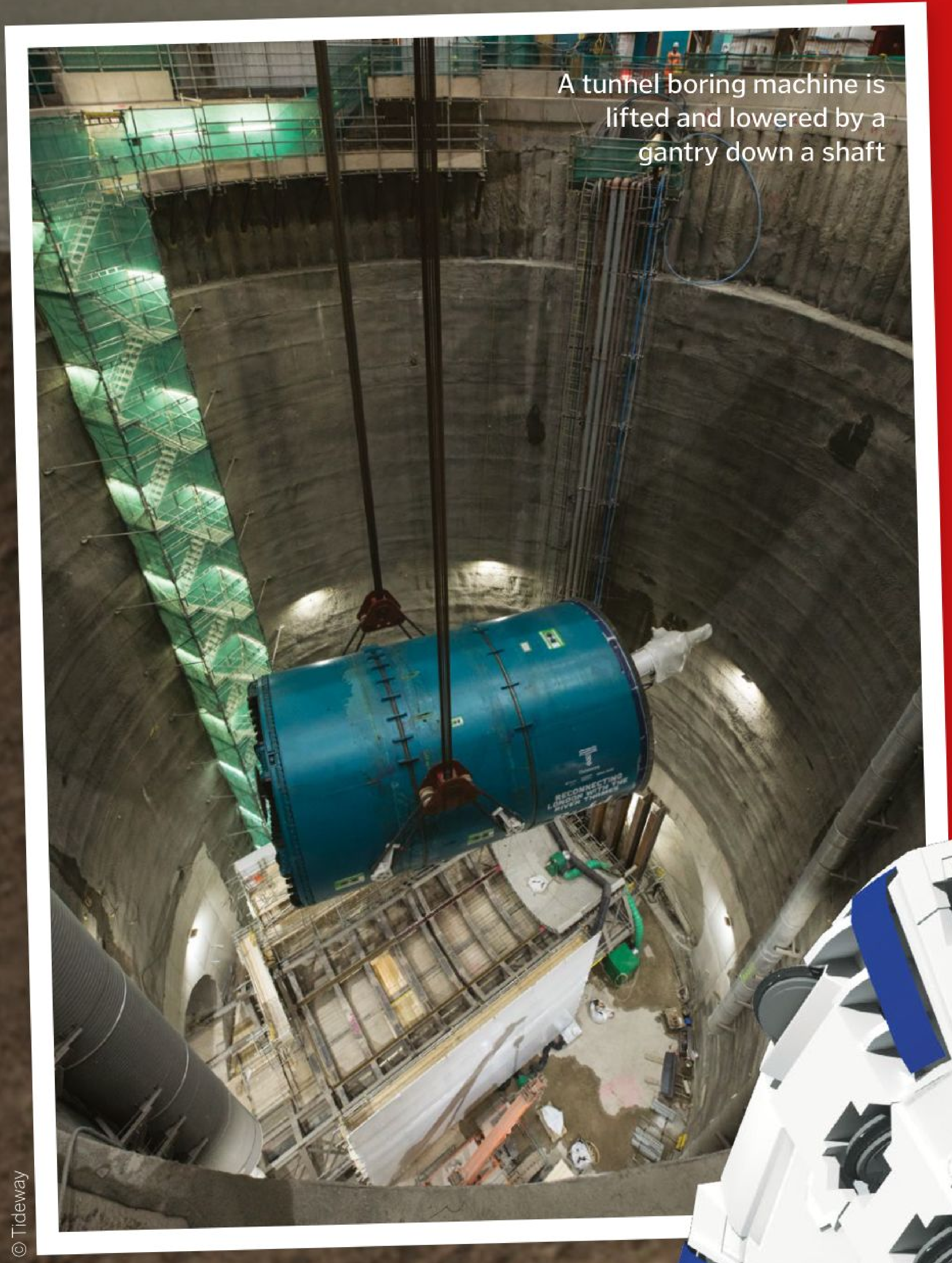
3. Deep shafts
Sewage will travel down and begin to fill deep shafts at various locations along the Thames.

Subterranean super-sewer

The new tunnel's route takes it from one side of London to the other


NEWHAM
TOWER HAMLETS
CITY OF LONDON
CITY OF WESTMINSTER
EALING
HOUNSLOW
KENSINGTON AND CHELSEA
HAMMERSMITH AND FULHAM
RICHMOND UPON THAMES
WANDSWORTH
LAMBETH
SOUTHWARK
LEWISHAM
GREENWICH
Lee Tunnel
The Limehouse Cut
Greenwich connection tunnel
Frogmore connection tunnel
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Map key
Main tunnel drive site
Main tunnel reception site
CSO site
Short connection tunnel drive site
Long connection tunnel drive site
System modifications
Main tunnel
Long connection tunnel
Lee Tunnel (under construction)
Proposed drive direction
West works site
Central works sites
East works site
1 Acton Storm Tanks
2 Hammersmith Pumping Station
3 Barn Elms
4 Putney Embankment Foreshore
5 Dormay Street
6 King George's Park
7 Carnwath Road Riverside
8 Falconbrook Pumping Station
9 Cremorne Wharf Depot
10 Chelsea Embankment Foreshore
11 Kirtling Street
12 Heathwall Pumping Station
13 Albert Embankment Foreshore
14 Victoria Embankment Foreshore
15 Blackfriars Bridge Foreshore
16 Shad Thames Pumping Station
17 Chambers Wharf
18 Earl Pumping Station
19 Deptford Church Street
20 Greenwich Pumping Station
21 King Edward Memorial Park Foreshore
22 Bekesbourne Street
23 Abbey Mills Pumping Station
24 Beckton Sewage Treatment Works

© All images Tideway



A tunnel boring machine is lifted and lowered by a gantry down a shaft

© Tideway

addition to the Victorian sewers, the new super-sewer is a prime example of engineering precision.

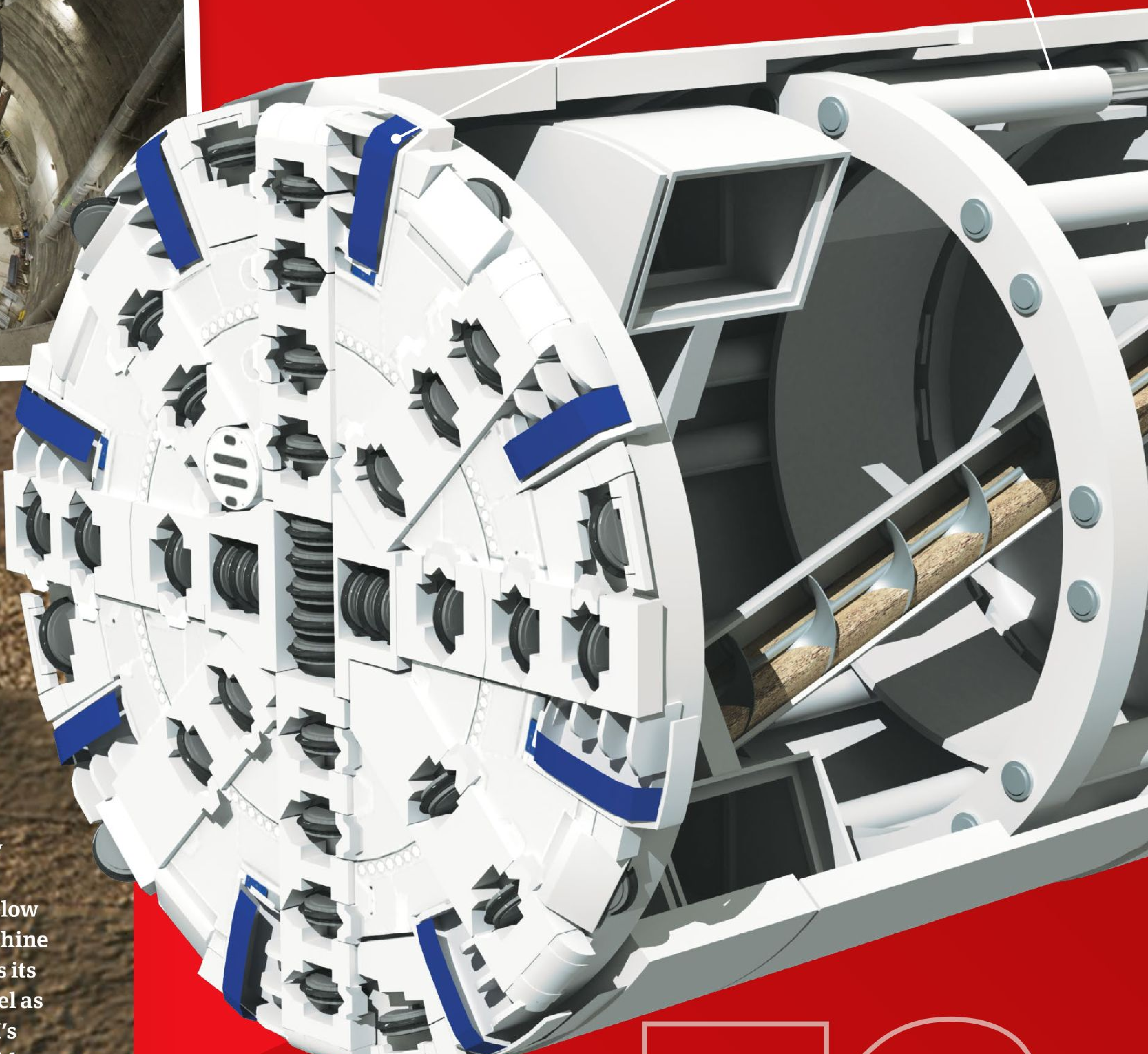
Beginning at Acton Storm Tanks in Ealing, the 25 kilometre-long tunnel will burrow beneath and follow the Thames until reaching Abbey Mills Pumping Station in Newham, London. Sewage collected throughout the tunnel will be sent down the Lee Tunnel, reaching its final destination at the Beckton Sewage Treatment Works.

In order to shape the Thames Tideway Tunnel, massive machinery has been brought in to carve into the rock deep below the river. Known as a tunnel boring machine (TBM), this burrowing behemoth pushes its way through bedrock, shaping the tunnel as it goes. What lies in the wake of the TBM's tunnelling force is tons of displaced rubble. Continually feeding through the belly of the metal beast, excavated material or slurry is carried on conveyor belts back to the surface.

Construction of the tunnel will create 4 million tons of rock and rubble that will need to be removed. Tideway is utilising the Thames to transport the material to landfill sites, via barges that can carry the equivalent to 50 heavy goods lorries. The rubble will then be used to cap off landfill sites, which will then be turned into nature reserves.

Giant Thames worm

Officially known as a tunnel boring machine (TBM), this mammoth vehicle can cut through bedrock, clearing the way for the new super-sewer under the Thames



Propulsion
The TBM moves with the help of hydraulic rams that push against the newly placed tunnel ring, moving it forward.

Cutter head
Made of steel, this circular, eight-metre mouth of earth-cutting teeth rotates, breaking down soil and rock to form the tunnel.

48 hours
The time taken to empty the tunnel when full

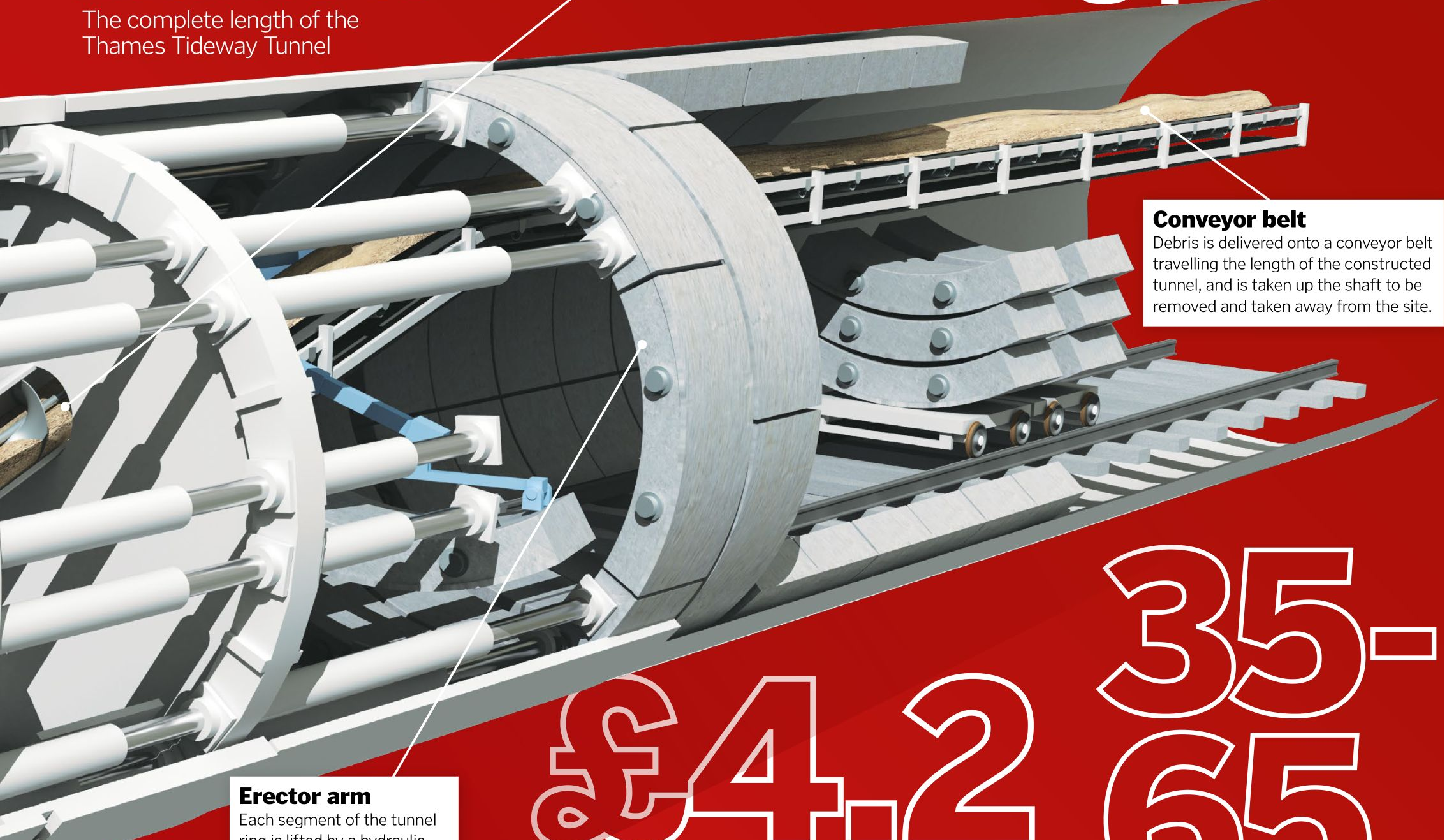
7.2 metres
The width of the tunnel

25 kilometres

The complete length of the Thames Tideway Tunnel

Thames Tideway Tunnel's storage capacity is equivalent to

600 Olympic-sized swimming pools



Screw conveyor
Broken-down rock and sediment travels up the 18-metre screw conveyor and is deposited on a conveyor belt.

Conveyor belt
Debris is delivered onto a conveyor belt travelling the length of the constructed tunnel, and is taken up the shaft to be removed and taken away from the site.

Erector arm
Each segment of the tunnel ring is lifted by a hydraulic arm and vacuum and secured in place.

£4.2 billion

Estimated cost to construct the new tunnel

35-65 metres

The depth below the ground the Thames tunnel will run

Constructing London's sewer system

1848
The Metropolitan Commission of Sewers is established to find a solution to London's serious sewage problem.

1858
Following a heatwave that results in the city's famous 'Great Stink', parliament approves the construction of a new London sewer system.

1859
Work begins on a new centralised sewer system, designed by the engineer Joseph Bazalgette.

1865
The first phase of Bazalgette sewer system is opened, comprising of 1,770 kilometres of street sewers and around 130 kilometres of underground main brick sewers.

2014
Plans are approved to construct the Thames Tideway Tunnel.

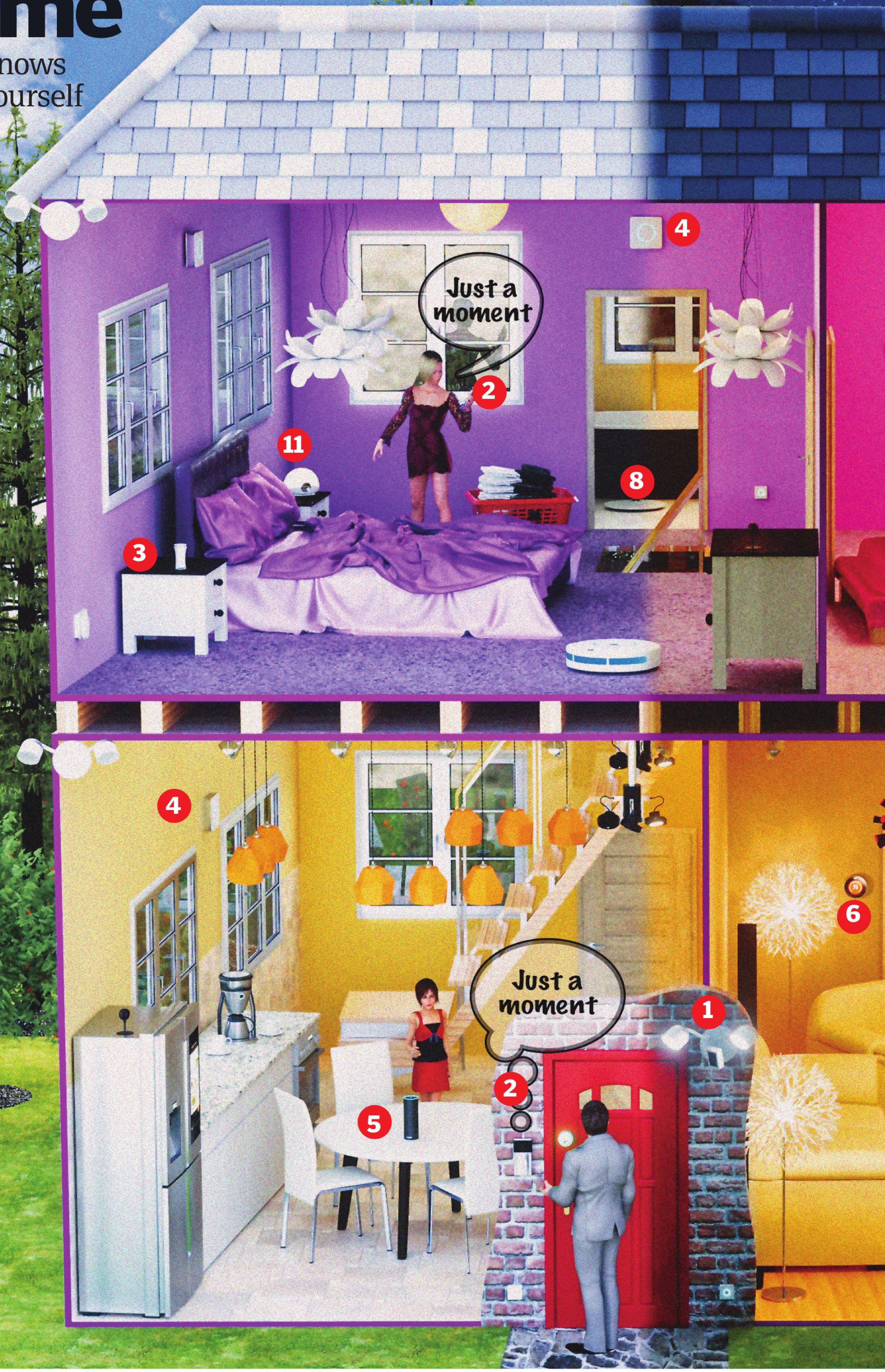
2016
Preliminary work begins to facilitate the tunnel's construction.

2018
The construction of the tunnel begins at Hammersmith Pumping Station.

2024
The target deadline for the completion of the Thames Tideway Tunnel.

Welcome to your future smart home

Step inside the house that knows you better than you know yourself



1 Upgrade your guard dog
Security cameras can keep an eye on your home 24/7, alerting you if there's movement and flooding the area with light to deter intruders.

2 Smart doorbell
A video doorbell allows you to see, hear and even speak to anyone at your door, even if you are not at home.

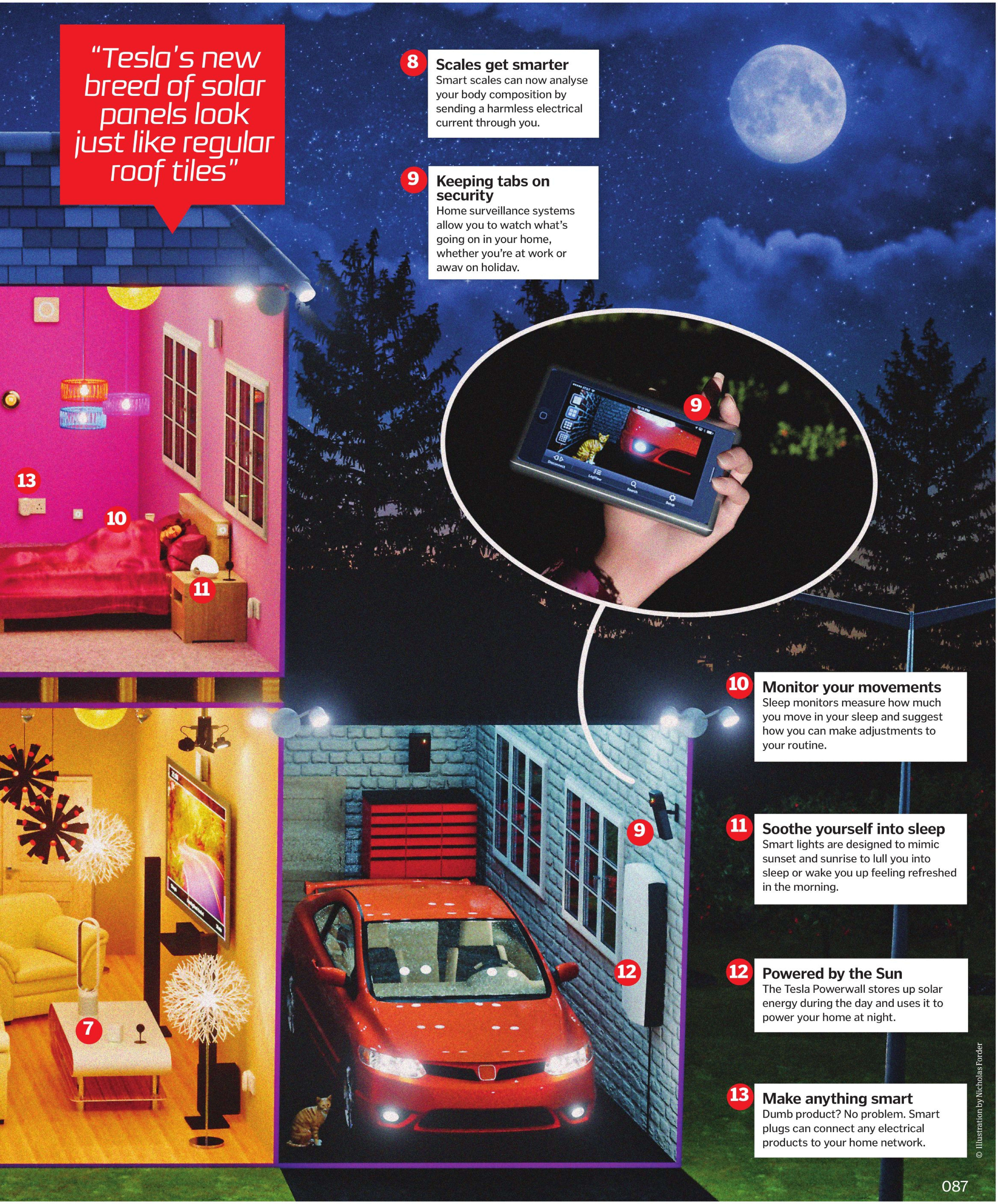
3 Air sensing
If you have allergies or asthma, the Cair Smart Air Quality Sensor can alert you as soon as issues arise.

4 Upgrade the smoke alarm
The Nest Protect is a smart smoke and carbon monoxide alarm that also doubles up as a night light.

5 Say hello to Alexa
Smart voice assistants act like the boss of your home, bringing all your connected products together.

6 Room temperature
Devices like the Nest thermostat learn your schedule, so they can make sure the heating is on when you need it, and turn it off when you don't.

7 Cleaner air
The Dyson Pure Cool Link promises to get rid of gas, allergens and pollution from the air in your home.



> “Tesla’s new breed of solar panels look just like regular roof tiles”

8 Scales get smarter

Smart scales can now analyse your body composition by sending a harmless electrical current through you.

9 Keeping tabs on security

Home surveillance systems allow you to watch what’s going on in your home, whether you’re at work or away on holiday.

10 Monitor your movements

Sleep monitors measure how much you move in your sleep and suggest how you can make adjustments to your routine.

11 Soothe yourself into sleep

Smart lights are designed to mimic sunset and sunrise to lull you into sleep or wake you up feeling refreshed in the morning.

12 Powered by the Sun

The Tesla Powerwall stores up solar energy during the day and uses it to power your home at night.

13 Make anything smart

Dumb product? No problem. Smart plugs can connect any electrical products to your home network.

© Illustration by Nicholas Forder

How do sewing machines work?

Ever wondered how a sewing machine can stitch fabric so quickly yet precisely? HIW reveals all

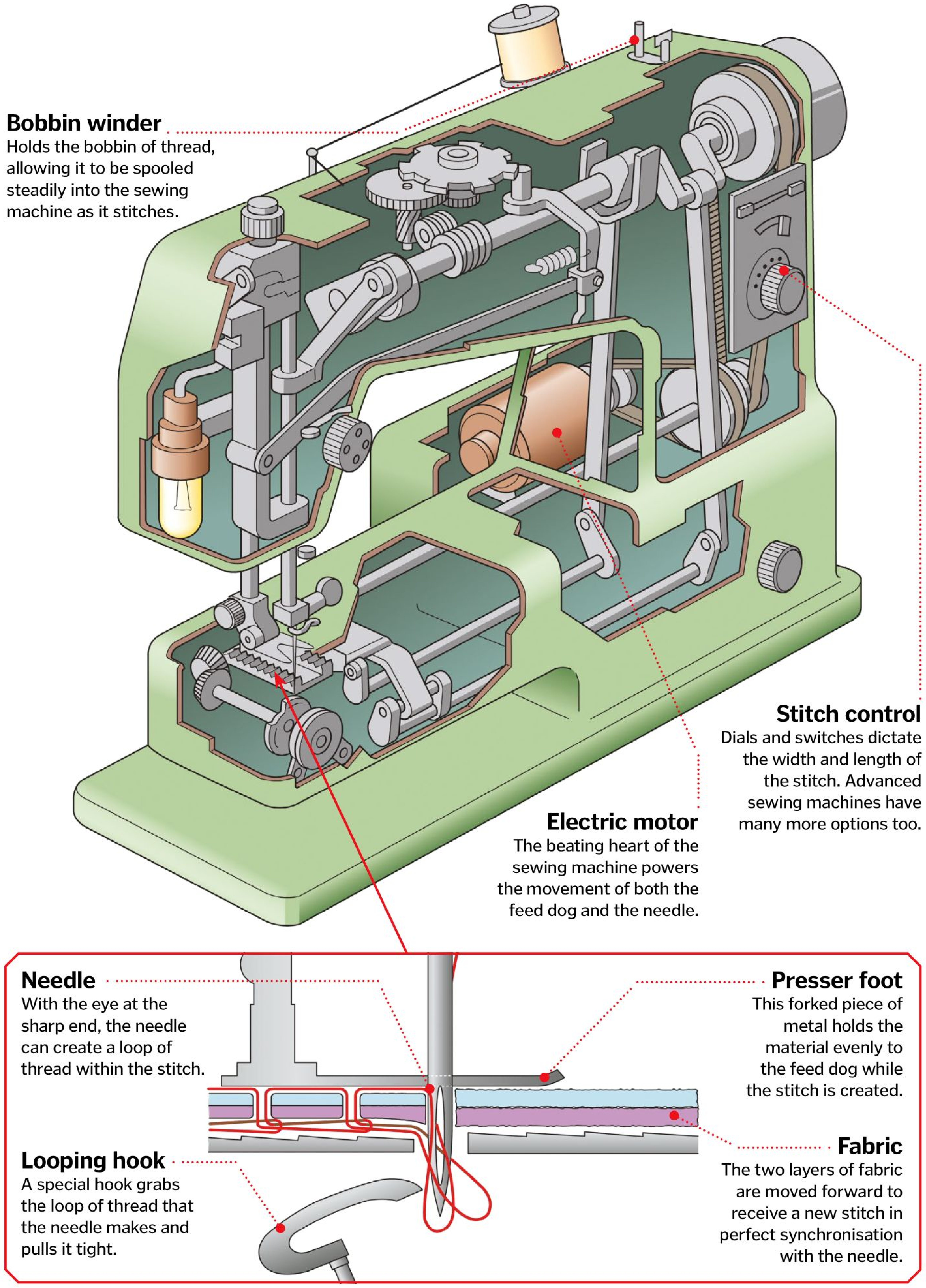
Modern sewing machines do the job of a highly skilled tailor in a fraction of the time. Before they were invented in the late-18th century, the fine stitching that we take for granted on our everyday clothes today would have only been available to the wealthiest members of society.

There are several basic methods of stitching that various models employ, but the loop stitch is the most common. This works by passing a needle tied with thread through both pieces of fabric and out the other side, then back again. When stitching manually this involves passing the needle to the other hand and turning it around to go back, which is too elaborate for a machine to perform, and also unnecessary.

Instead a sewing machine uses two parts: a needle and a looping hook. The machine needle passes only partway through the material with the eye at the sharp end rather than the blunt end like its handheld equivalent. As it's moving through the fabric, the needle drags a loop of thread to the other side, where a hook grabs it and either loops the thread around itself or around a separate piece of thread. The needle then retracts and the thread is drawn tight, fastening the fabric together.

Inside a sewing machine

We walk you through the vital components that drive one of these mechanised tailors



Bobbin winder
Holds the bobbin of thread, allowing it to be spooled steadily into the sewing machine as it stitches.

Stitch control
Dials and switches dictate the width and length of the stitch. Advanced sewing machines have many more options too.

Electric motor
The beating heart of the sewing machine powers the movement of both the feed dog and the needle.

Needle
With the eye at the sharp end, the needle can create a loop of thread within the stitch.

Presser foot
This forked piece of metal holds the material evenly to the feed dog while the stitch is created.

Looping hook
A special hook grabs the loop of thread that the needle makes and pulls it tight.

Fabric
The two layers of fabric are moved forward to receive a new stitch in perfect synchronisation with the needle.

© Peters & Zabransky; Thinkstock

What is the feed dog?

Inside an electric sewing machine is a sophisticated series of gears and shafts that all connect to a single motor. One part of the motor controls a crank that pulls the needle bar up and down, plus a thread-tightening arm, which creates a slack loop and then tightens it to form the stitch. The other vital part of the sewing machine that the motor controls is the feed dog. This is the belt that steadily and evenly moves the fabric forward in synchronisation with the needle to create a new stitch. The feed dog is pressed up against the fabric where it rolls forward, shifting the material a short, consistent distance before dropping down again to release it. The entire process of feed dog, needle bar and thread-tightening arm is entirely driven by the motor, which in turn is controlled by a pressure-sensitive footplate operated by the user.

RECORD BREAKERS
KING OF COAL

3,523mn

BIGGEST COAL PRODUCER

China mined a staggering 3,523 million tons of coal in 2018, significantly ahead of India, which extracted just 716 million tons. The world total was 7,727 million tons.

DID YOU KNOW? *A lot of the coal we extract for fuel today originates from the Carboniferous period 360-300mn years ago*

Exploring a coal mine

Coal fuelled the Industrial Revolution and even today is responsible for 40 per cent of the world's electricity, but how is a colliery laid out?

There are two basic types of coal mines, also known as collieries. The first is the opencast surface mine, which consists of a coal seam covered by an overburden layer of soil and rock. Bulldozers clear the soil and explosives are used to break up the remaining overburden. Draglines and power shovels are then brought in to remove this material, followed by the extraction of the coal. After the mine is exhausted the topsoil is returned to landscape the area.

The second type, the underground mine (shown here), can access deeper seams of coal and is far more dangerous and challenging. Originally, the coal face was dug by pick and shovel, but as time went by, explosives were used to blast away at the coal seam.

Modern mines use machines that have tungsten bits that cut into the coal face. Longwall and room-and-pillar systems are the two main methods for extracting coal. The longwall method slices horizontally into the coal face and drops the mineral onto conveyer belts. The room-and-pillar method cuts a grid-like network of tunnels in the coal seam, leaving the remaining pillars to support the roof. The longwall method can be used to finish off the pillars that are left behind by the room-and-pillar technique.

Fire in the hole!

Coal seams can catch fire and burn for decades or even centuries, either due to accidental causes such as gas explosions or natural causes when there is sufficient heat and ventilation to bring about self-combustion.

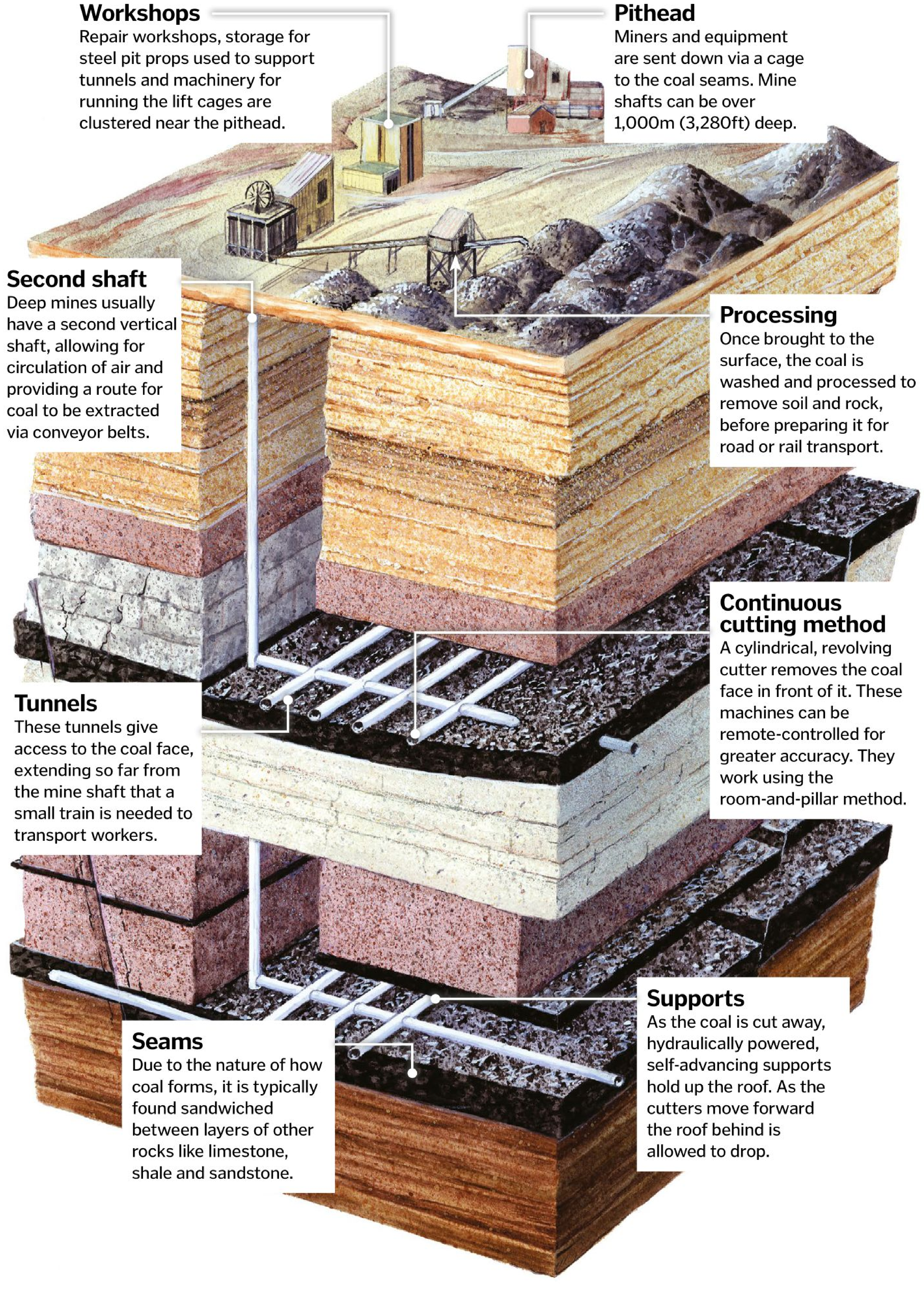
Incredibly thousands of worldwide seam fires account for as much as three per cent of carbon dioxide emissions. They also belch out other toxic gases and cause subsidence and destruction to their local landscapes.

They only stop burning when they exhaust their coal reserves or are extinguished through human intervention. Deep mine fires are put out by isolating them and pumping inert gases around the area of the blaze.

Fires nearer the surface, on the other hand, can be dealt with by pumping mud and water into the ground, followed by covering the area with an impermeable layer of sediments. The extent and depth of many of these fires though means they are impossible to put out.

Coal mine level by level

Take a tour of the main areas that make up a colliery



Workshops
Repair workshops, storage for steel pit props used to support tunnels and machinery for running the lift cages are clustered near the pithead.

Pithead
Miners and equipment are sent down via a cage to the coal seams. Mine shafts can be over 1,000m (3,280ft) deep.

Second shaft
Deep mines usually have a second vertical shaft, allowing for circulation of air and providing a route for coal to be extracted via conveyor belts.

Processing
Once brought to the surface, the coal is washed and processed to remove soil and rock, before preparing it for road or rail transport.

Continuous cutting method
A cylindrical, revolving cutter removes the coal face in front of it. These machines can be remote-controlled for greater accuracy. They work using the room-and-pillar method.

Tunnels
These tunnels give access to the coal face, extending so far from the mine shaft that a small train is needed to transport workers.

Supports
As the coal is cut away, hydraulically powered, self-advancing supports hold up the roof. As the cutters move forward the roof behind is allowed to drop.

Seams
Due to the nature of how coal forms, it is typically found sandwiched between layers of other rocks like limestone, shale and sandstone.

© SPL

Hoover Dam construction

It was one of the most ambitious projects in the world, but how was the Hoover Dam constructed?

In the early-20th century, the lower region of the Colorado River was considered as a site for flood control and potential source of hydroelectric power for the growing demands of western US states. What would be known as the Hoover Dam was authorised by President Calvin Coolidge in 1928 and construction began by building conglomerate Six Companies in March 1931.

At the time the Hoover Dam was the largest in the world requiring over 3.3 million cubic metres (118 million cubic feet) of concrete to build, including the power station.

Before the dam could be built, foundations had to be laid and over 1.3 million cubic metres (48 million cubic feet) of loose rock and sediment were removed from the bottom of the Colorado River to reach stable bedrock. The foundation was reinforced with a grout curtain and the canyon walls were similarly stabilised by drilling holes up to 46 metres (150 feet) deep into them and filling cavities with more grout. Chief engineer John Savage had decided it would be an arch-gravity dam, which combines the main features of two different types of dam: the arch part is a concave face that leans towards the water, deflecting some of the pressure onto the canyon walls, while the gravity part of the design is the enormous weight of the dam that thickens considerably from the top (13.7 metres/45 feet) to the bottom (201 metres/660 feet). This helps to resist the immense force that the Colorado River can generate with its 5.5 million-ton weight.

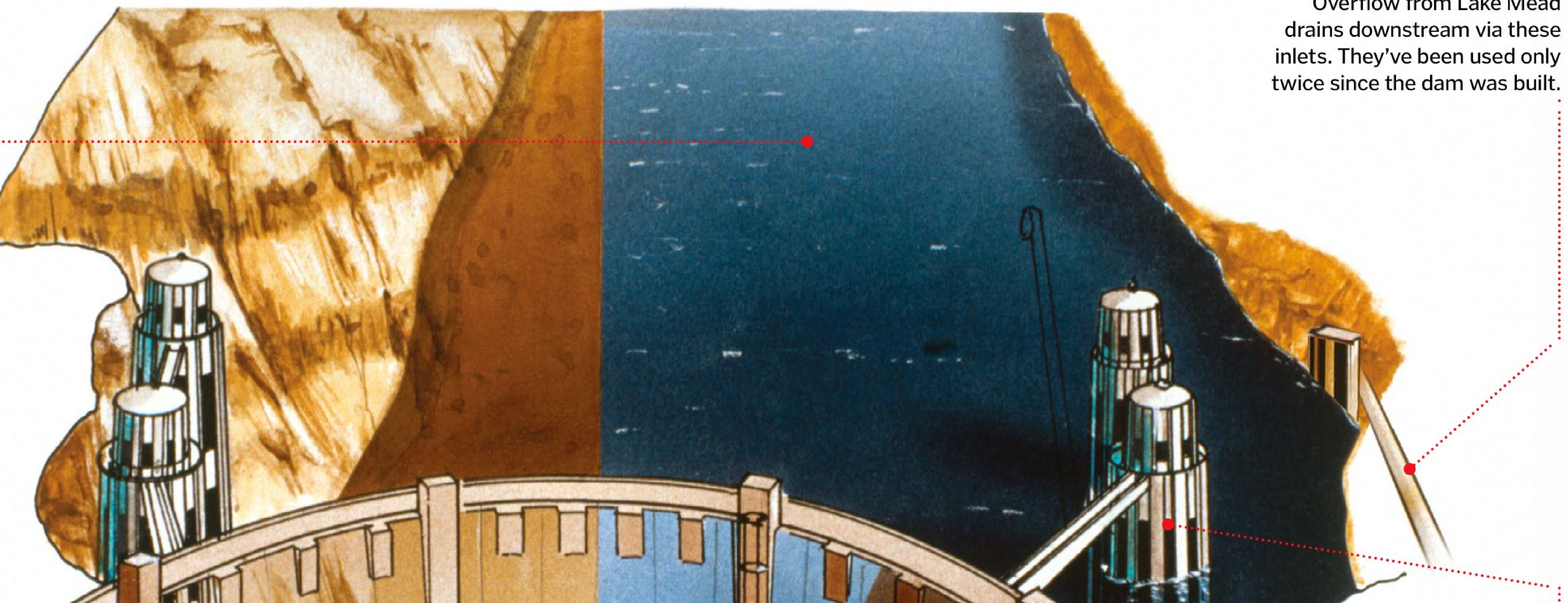
To help dissipate the heat generated by all this concrete setting, around 950 kilometres (590 miles) of steel piping delivered water cooled by the dam's dedicated ammonia refrigeration plant through the 230 concrete blocks that make up the structure. Without this active cooling system in place, all that concrete would still be setting today!

Diverting the Colorado River

Constructing the Hoover Dam would have been impossible with the Colorado River still flowing through Black Canyon. So, the builder endeavoured to divert the course of the river. Four tunnels with a combined length of over five kilometres (three miles) were dug into the canyon walls and around the dam site. The river was diverted into these tunnels by blocking its natural course with rubble as well as detonating a hole in a cofferdam – a temporary enclosure that stopped the river draining into the diversion tunnels. This was only performed for the two tunnels on the Arizona side of the canyon. The two drainage tunnels on the Nevada side were held in reserve for the higher waters in spring and summer.

Hoover Dam structure

How It Works explores one of the world's greatest engineering feats



Lake Mead
At maximum capacity, the lake on the upstream side of the dam can yield 219,700kg/m² (45,000lb/ft²) of force at its base.

Spillway inlet
Overflow from Lake Mead drains downstream via these inlets. They've been used only twice since the dam was built.

KEY DATES
HOOVER DAM

1928
A dam in Black Canyon is authorised by Congress and Six Companies wins the contract.

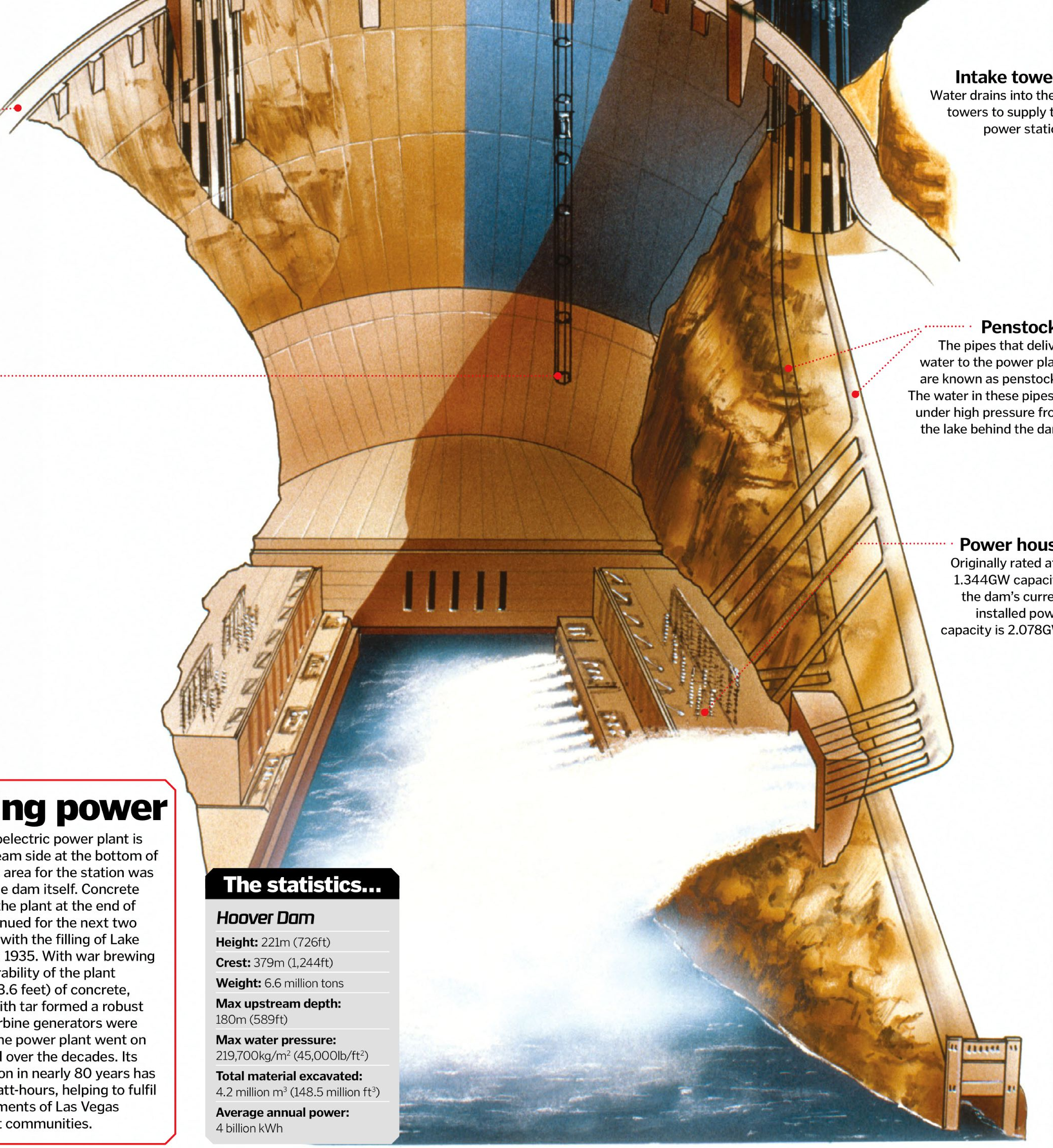
1935
President Roosevelt (right) formally opens the dam on 30 September to a crowd of 10,000.

1947
The 'Boulder Dam' name is removed and the House of Congress bestows the name 'Hoover Dam' instead.

1961
The last of the 17 turbines is installed into the power station, bringing it up to full capacity.

1983
The 1983 floods see the Hoover Dam use its spillways for only the second time (the first being a 1941 test).

DID YOU KNOW? *The Hoover Dam was initially called Boulder Dam, as Boulder Canyon was the original site location*



Intake towers
Water drains into these towers to supply the power station.

Penstocks
The pipes that deliver water to the power plant are known as penstocks. The water in these pipes is under high pressure from the lake behind the dam.

Power house
Originally rated at a 1.344GW capacity, the dam's current installed power capacity is 2.078GW.

Highway
For many years the top of the Hoover Dam served as a public highway between Nevada and Arizona until the Hoover Dam Bypass was opened in 2010.

Elevator
An elevator takes tourists down a 152m (500ft) shaft to the base of the dam to the power plant.

Generating power

The Hoover Dam's hydroelectric power plant is located on the downstream side at the bottom of the dam. Excavating the area for the station was finished in 1933, after the dam itself. Concrete began to be poured for the plant at the end of the same year and continued for the next two years, even overlapping with the filling of Lake Mead behind the dam in 1935. With war brewing in Europe and the vulnerability of the plant considered, 1.1 metres (3.6 feet) of concrete, rock and steel topped with tar formed a robust ceiling. Three Francis turbine generators were installed in 1937 when the power plant went on line, with 14 more added over the decades. Its average power generation in nearly 80 years has been around four terawatt-hours, helping to fulfil the huge power requirements of Las Vegas among other west coast communities.

The statistics...

Hoover Dam

Height: 221m (726ft)

Crest: 379m (1,244ft)

Weight: 6.6 million tons

Max upstream depth: 180m (589ft)

Max water pressure: 219,700kg/m² (45,000lb/ft²)

Total material excavated: 4.2 million m³ (148.5 million ft³)

Average annual power: 4 billion kWh

© Thinkstock

Stand mixers

Discover how this useful kitchen gadget transformed the way we bake

Baking can be hard work, particularly when you have to mix all of the ingredients together by hand. If you're planning to make a lot of cakes, cookies and other tasty treats at home, then a stand mixer could be a worthwhile investment, as it will certainly save your mixing arm from getting tired.

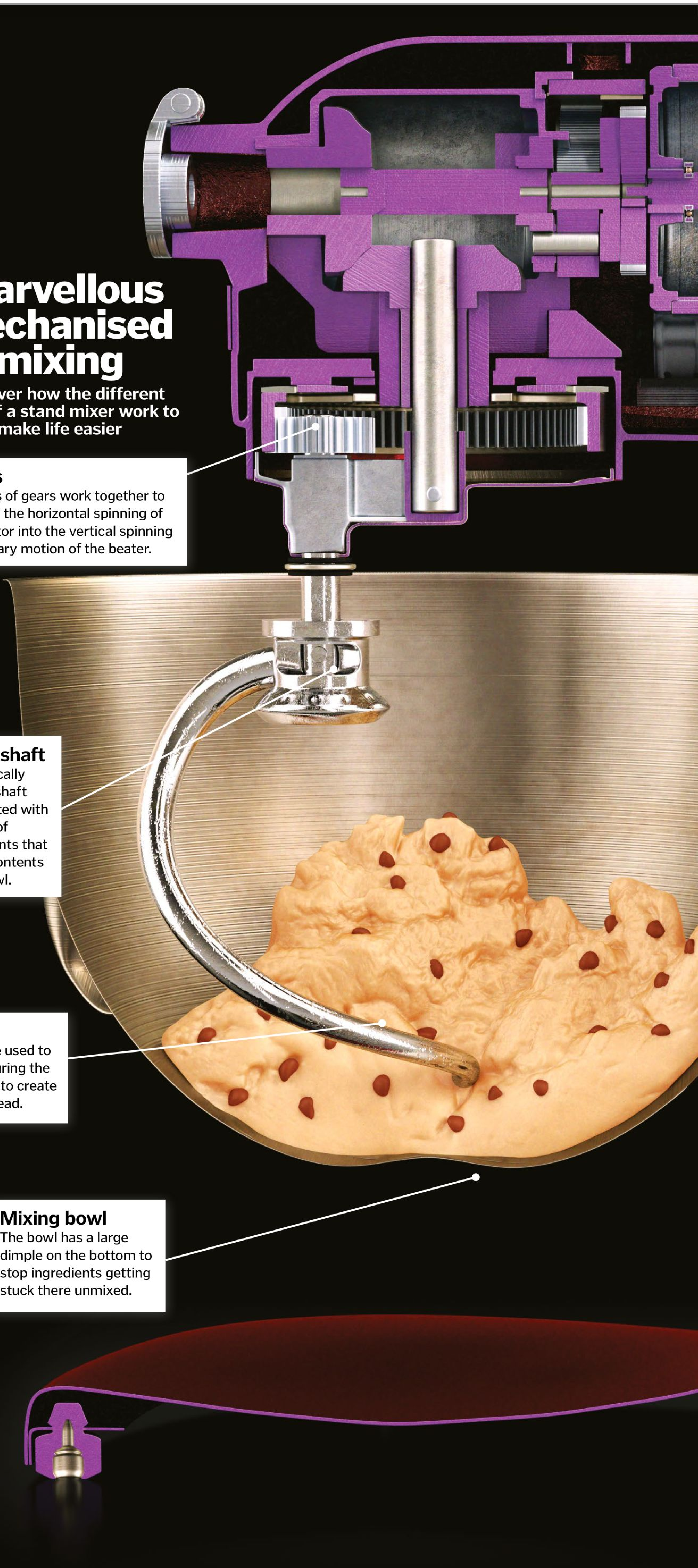
Stand mixers differ from food processors because they are designed to combine ingredients using a beater rather than chop them using a blade, which makes them ideal for baking. They work in much the same way as their handheld electric counterparts, with a motor that drives a set of gears causing a mixing attachment to rotate. When placed in your bowl of ingredients, the spinning attachment combines everything together to create a dough, batter or any other type of mix. The benefit of a stand mixer is that you don't need to hold it while it works, freeing up your hands to get on with other tasks. They also allow you to mix together your ingredients at a choice of different consistent speeds, helping to make sure your bakes are perfect every time.

The very first food mixers, called egg beaters, were patented in 1884 and were operated by hand. To mix your ingredients you had to crank a wheel that would then turn a set of gears and rotate the beaters. Eventually, an electric version was introduced, and then in 1908 the stand mixer was invented.

Herbert Johnson, an engineer at the Hobart Manufacturing Company, came up with the idea after watching an exhausted baker trying to mix some bread dough with a spoon. It wasn't long before his new mixer had revolutionised the baking industry, and in 1919 a domestic version was created for home cooks too.

Marvellous mechanised mixing

Discover how the different parts of a stand mixer work to make life easier



Gears
A series of gears work together to convert the horizontal spinning of the motor into the vertical spinning and rotary motion of the beater.

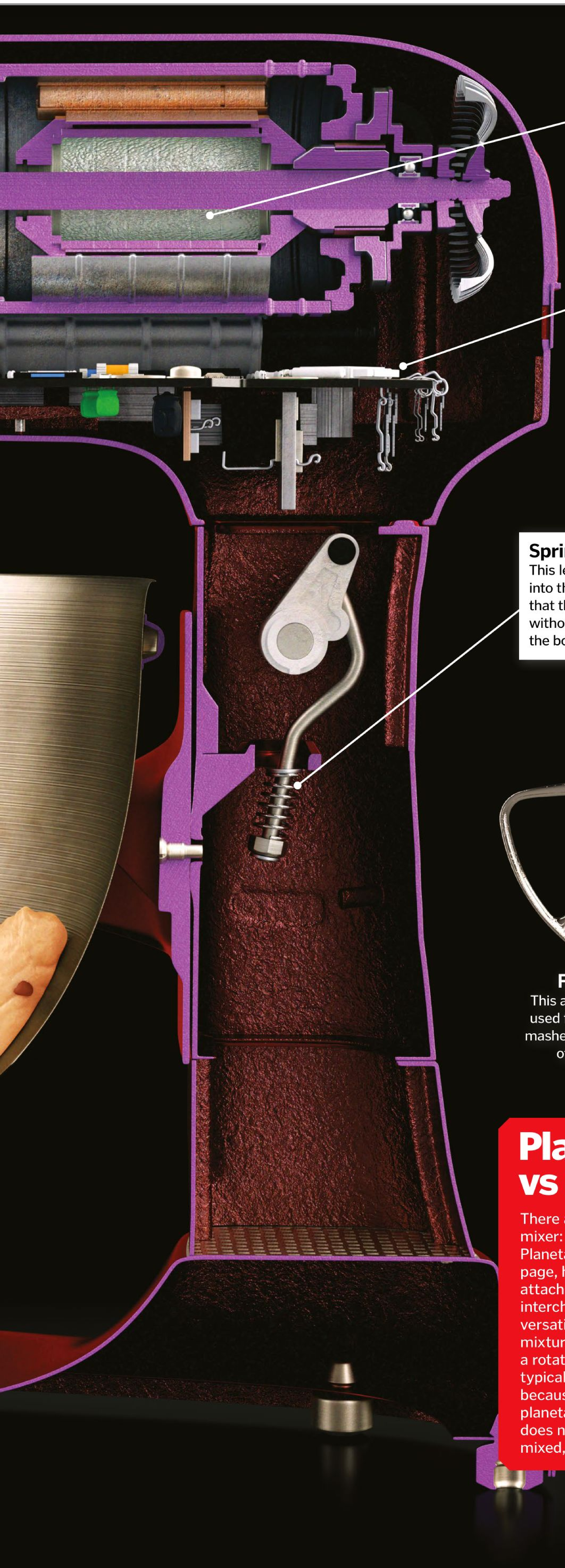
Beater shaft
This vertically spinning shaft can be fitted with a variety of attachments that mix the contents of the bowl.

Hook
The hook can be used to mix dough, ensuring the gluten develops to create fluffy, chewy bread.

Mixing bowl
The bowl has a large dimple on the bottom to stop ingredients getting stuck there unmixed.

Stand mixers take the hard work out of baking

DID YOU KNOW? *The first stand mixers were installed on US navy ships to help feed the troops during the First World War*



Motor
Here electrical energy is converted into mechanical energy, producing the spinning action of the gears.

Speed sensor
This sensor monitors the motor's spinning speed and transmits information to and from the mixer's control panel.

Spring-loaded lever
This lever locks the bowl into the correct position so that the beater can do its job without hitting the sides of the bowl.

Spiral mixers are a type of stand mixer used for making bread

> *"The benefit of a stand mixer is that you don't need to hold it while it works"*

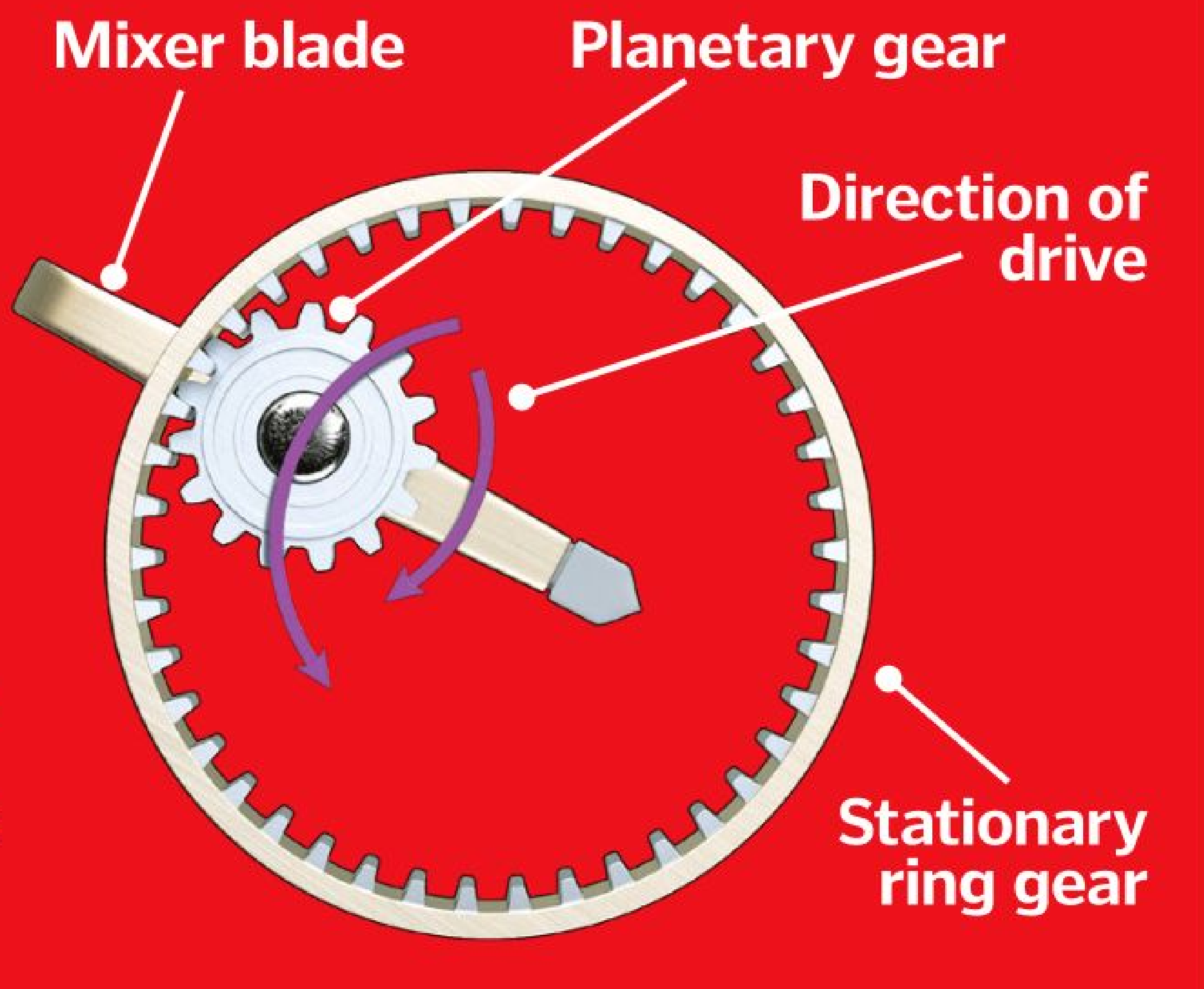
Flat beater
This attachment can be used for cakes, cookies, mashed potato and many other mixtures.

Flex-edge beater
This attachment's flex-edge will help to scrape a mixture off the sides of the bowl.

Wire whisk
The whisk attachment whips air into liquid mixtures to create meringues and sauces.

Planetary mixers vs spiral mixers

There are in fact two different types of stand mixer: planetary mixers and spiral mixers. Planetary mixers, like the one featured on this page, have a fixed bowl and a rotating attachment. As the attachment is interchangeable, this type of mixer is very versatile as it can create a wide range of mixtures. Spiral mixers, on the other hand, have a rotating bowl and a fixed, static attachment, typically a hook. They are ideal for making bread because they create less friction than a planetary mixer. This ensures that the dough does not increase in temperature while being mixed, allowing it to rise properly when baking.



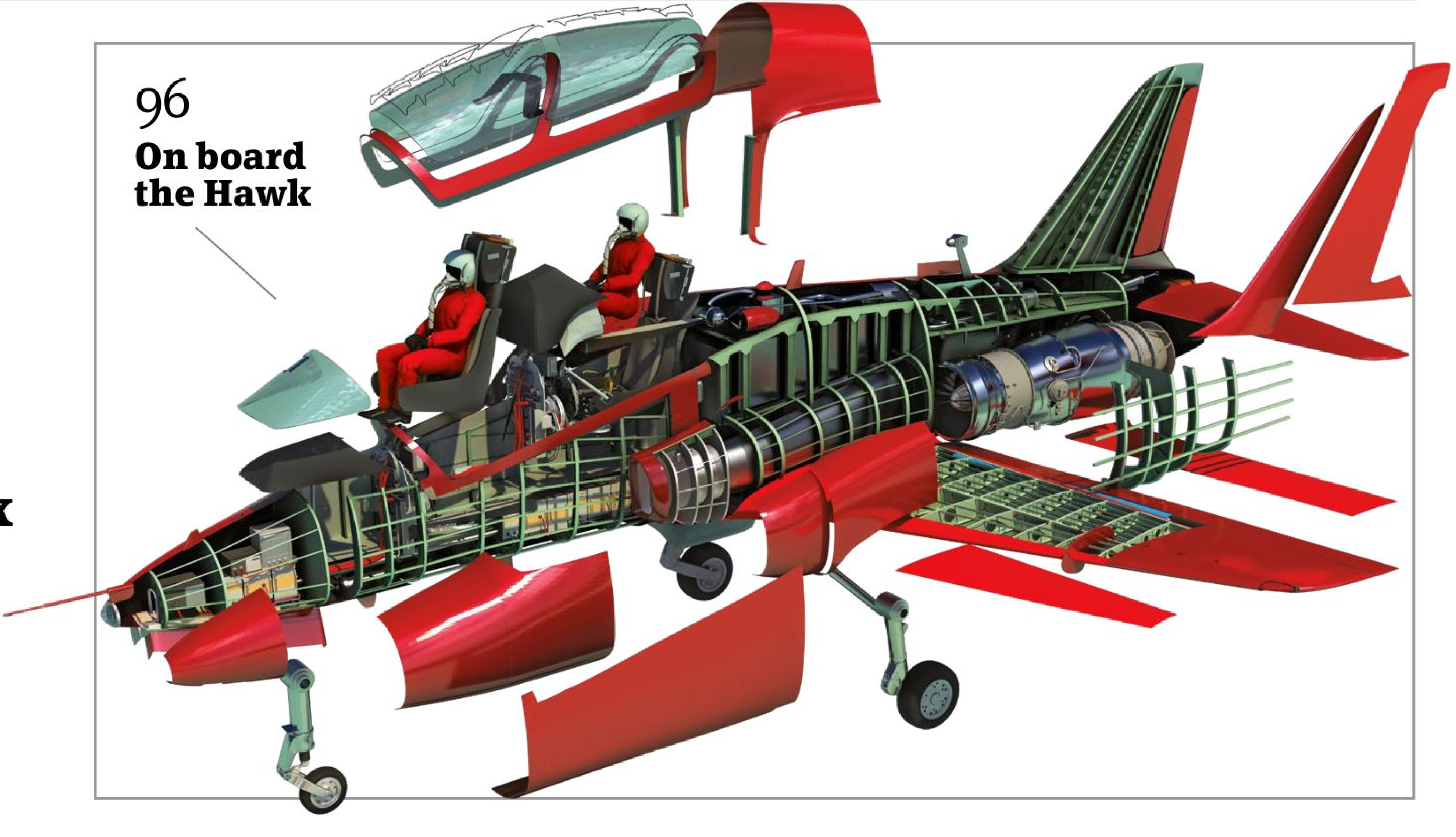
Planetary mixers use a series of gears to drive the rotating attachment

© Getty; Illustrations by Nicholas Forder

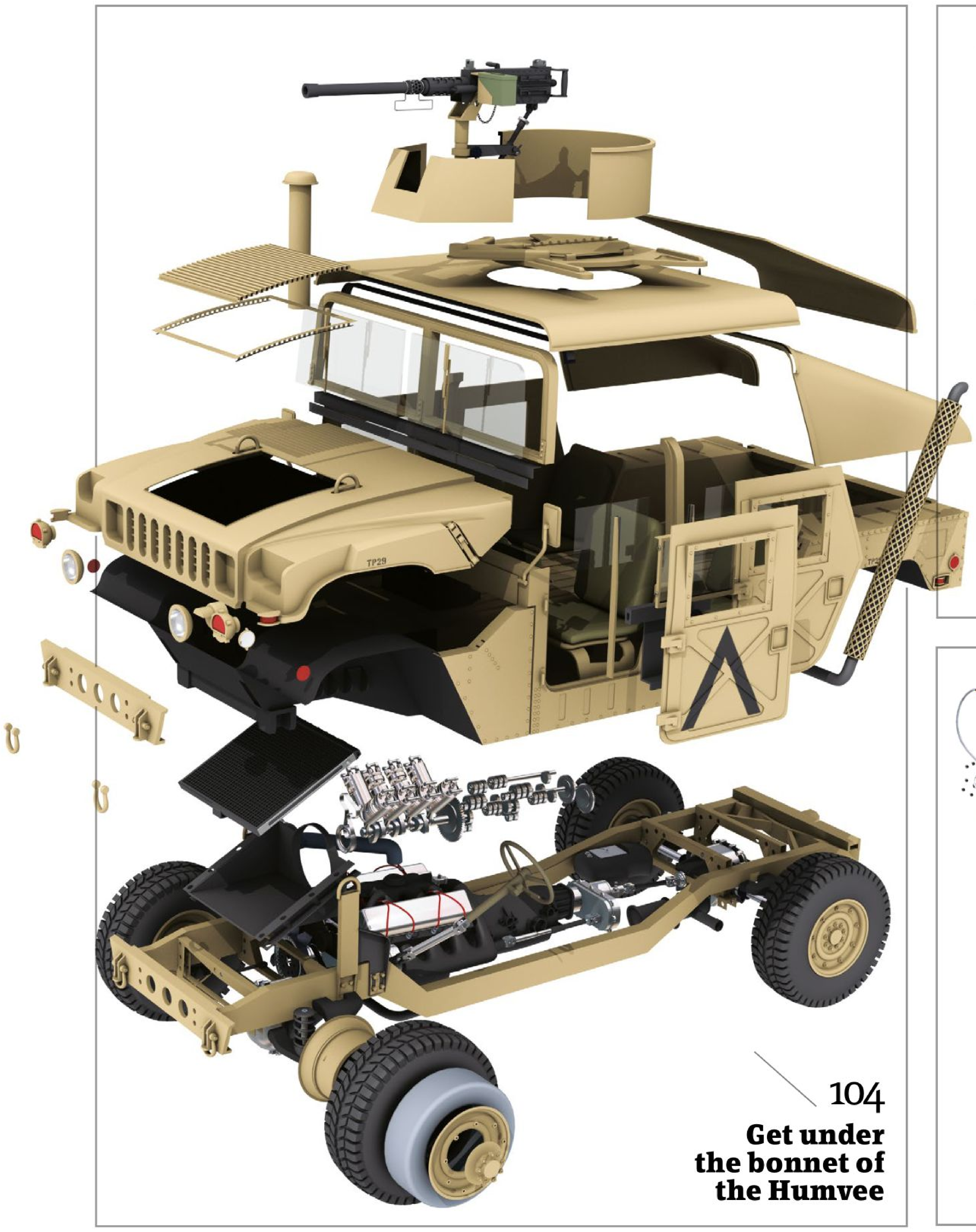
TRANSPORT

116
How superyachts combine luxury with the latest tech

96 **Inside a Red Arrow**
100 **Inside the I-PACE**
102 **Explore the RRS Sir David Attenborough**
104 **The Humvee**
106 **Snow groomers**
108 **How helicopters fly**
110 **How go-karts work**
112 **Abrams M1 Battletank**
114 **C-130 Hercules**
116 **What makes a superyacht?**
118 **F-22 Raptor vs F-35 Lightning II**

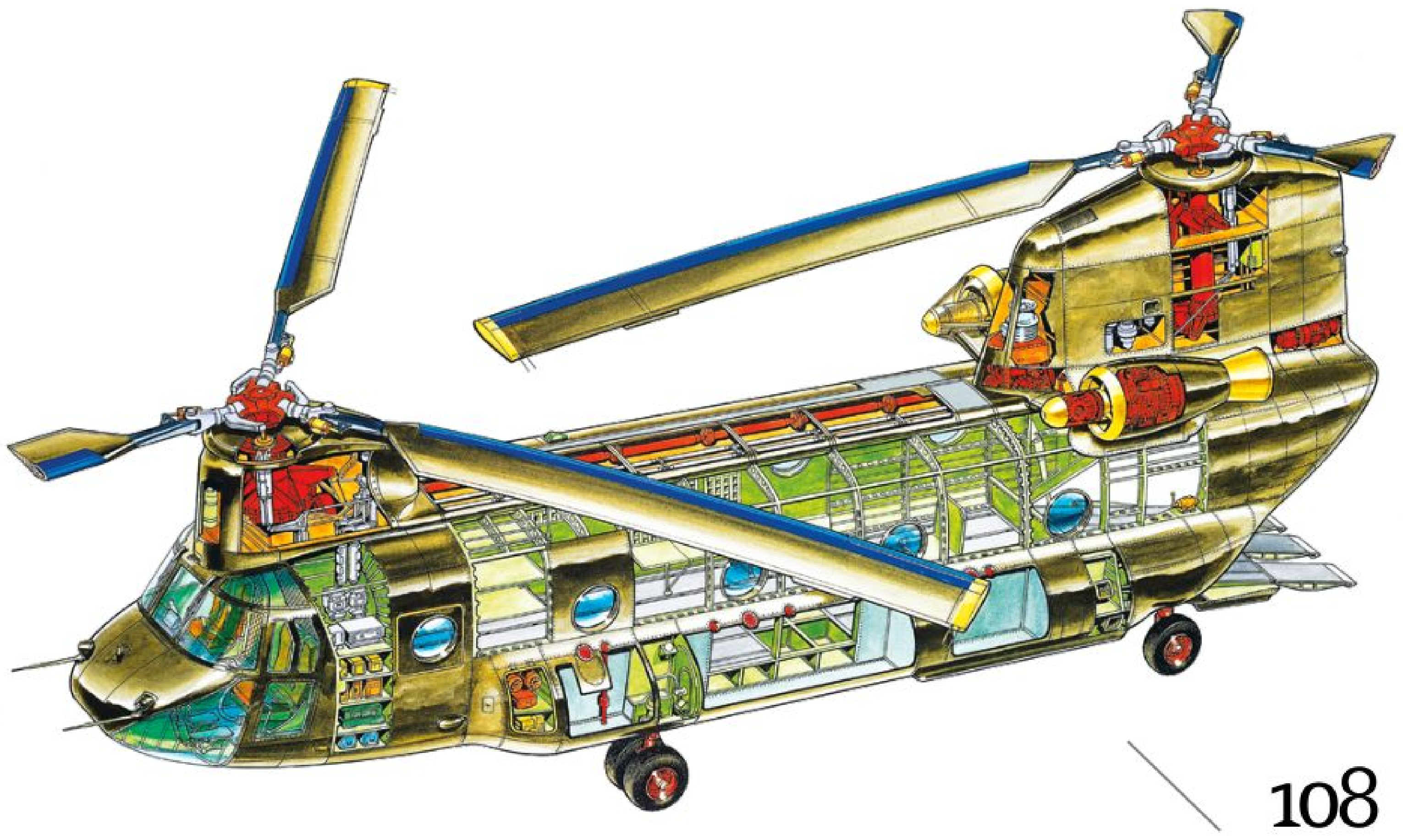


96
On board the Hawk



104

Get under the bonnet of the Humvee



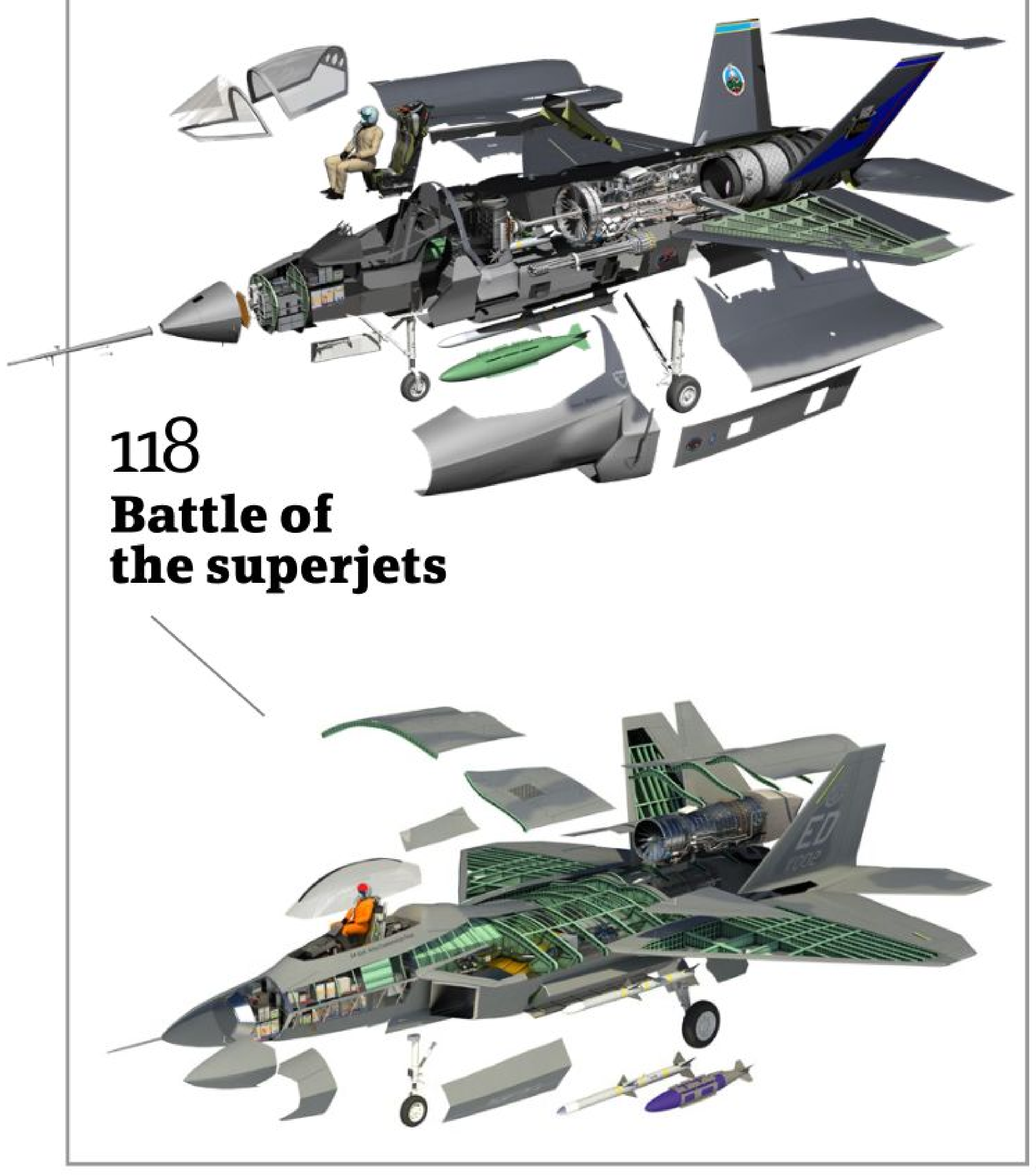
108

Discover the science behind helicopter flight

ZTECH
1
FUTURE
BRIDGESTONE

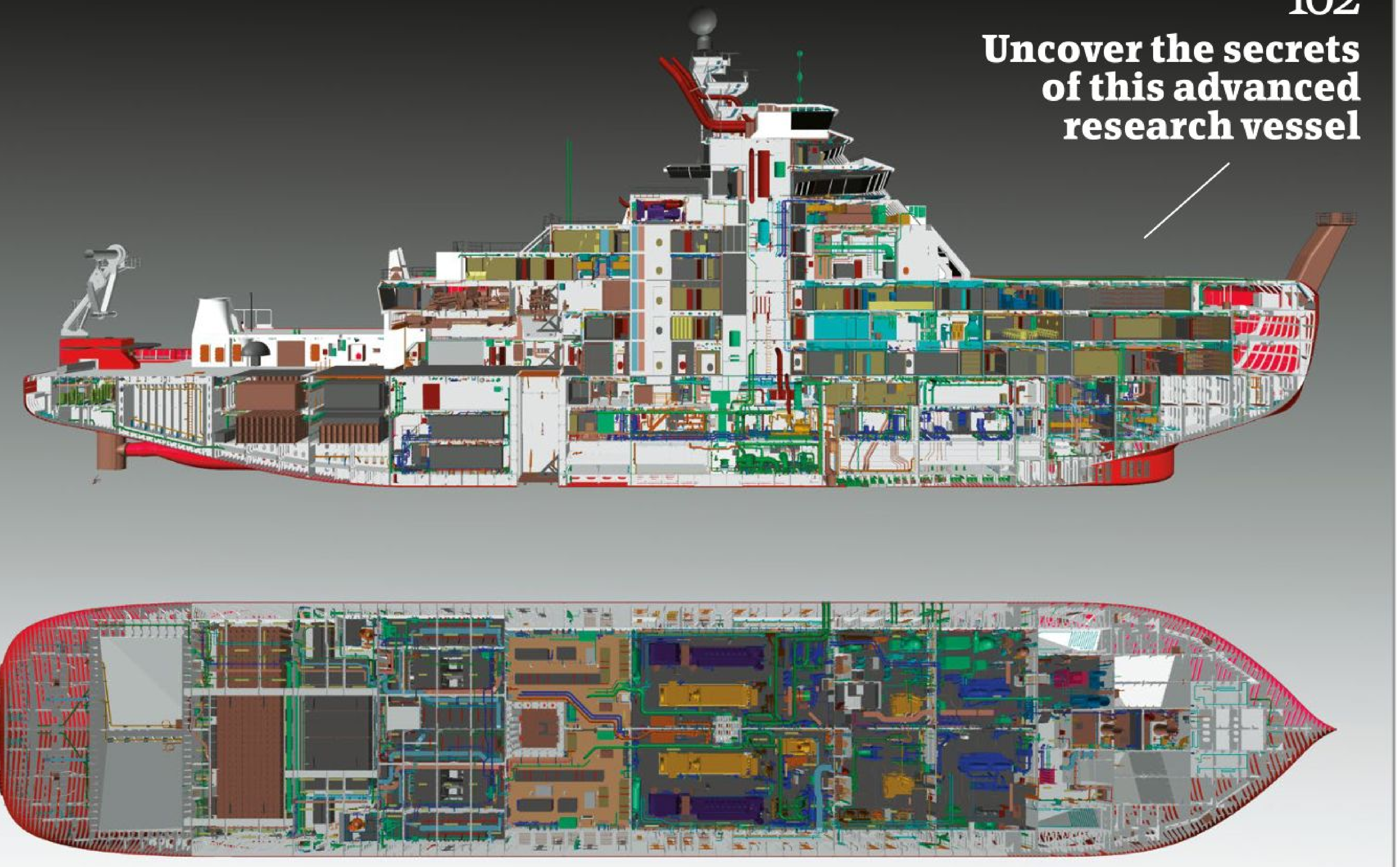
110

The mechanics of a go-kart



118

Battle of the superjets



102

Uncover the secrets of this advanced research vessel

On board the HAWK

The dual-control training jet that helps the next generation of pilots prepare for combat

Words by **Scott Dutfield**

Getting into the cockpit of a jet engine aircraft for the first time is a daunting prospect for any trainee pilot. After spending years learning the theoretical physics and basics of flying, the Hawk is the next stage in their training and their first real venture into the skies, in a working military jet.

The Hawk has played a key training role within the Royal Air Force (RAF) since the 1970s. Originally designed and constructed by Hawker Siddeley Aviation Limited (now known as BAE Systems) in 1971 and first flown in 1974, the Hawk promised a more agile way to fly. It replaced the Folland Gnat, a plane similar in weight and size. However, the Gnat's cockpit only offered a single seat, leaving inexperienced pilots to fly solo. The Gnat saw the end of its training career in 1979 when the new, purpose-built Hawk T1 swooped in to take over.

What makes the Hawk unique for training the next generation of RAF pilots is its dual-control capabilities. Similar to the dual-control cars used by driving instructors, the two-man tandem cockpit enables a teaching pilot to sit behind their student and intervene when needed. For teaching the basics, the jet's cockpit is relatively unchanged since the plane's introduction to the Air Force. Pilots rely on dials, gauges and the view through the glass roof to navigate and fly the plane. However, BAE Systems has integrated multi-functional digital displays in the newer model, the Hawk T2.

Offering an introduction to fast jets, the Hawk is designed to reach Mach 0.88 during flight and Mach 1.15 during a dive. The Mach number relates to the jet's speed when compared to that of sound (equal to Mach 1), so the Hawk can manoeuvre at speeds known as transonic, paving the way for pilot training on supersonic jets such as the F-35 Lightning II.

Although predominantly used as training jet, the Hawk has proven itself as a combat aircraft and has also been used for reconnaissance and surveillance. Currently, around 1,000 aircraft have been sold to 18 countries across the globe.

ROYAL AIR FORCE
XX311
XX242

Aerial acrobats

Though they triumph as a training jet, the Hawk is most recognised as the type of plane seen flying in formation during a Red Arrows display. Originally sporting a black coat of paint, the newly introduced Hawk T1 had a red makeover upon joining the ranks of the Royal Air Force Aerobatic Team in 1979. Debuting synchronised sky routines a year later, the Hawk T1 proved its ability to perform stunning displays.

These gravity-defying stunts, however, can be limited by the weather. In order to carry out the iconic loops, the cloud base needs to be above 1,700 metres so the aircraft avoid entering it and disappearing from sight. If the clouds are lower than that, they're limited to rolling displays, flypasts and steep turns.

© Getty

An RAF Hawk T1 training aircraft, which has been painted black to make it easily visible and reduce accidents

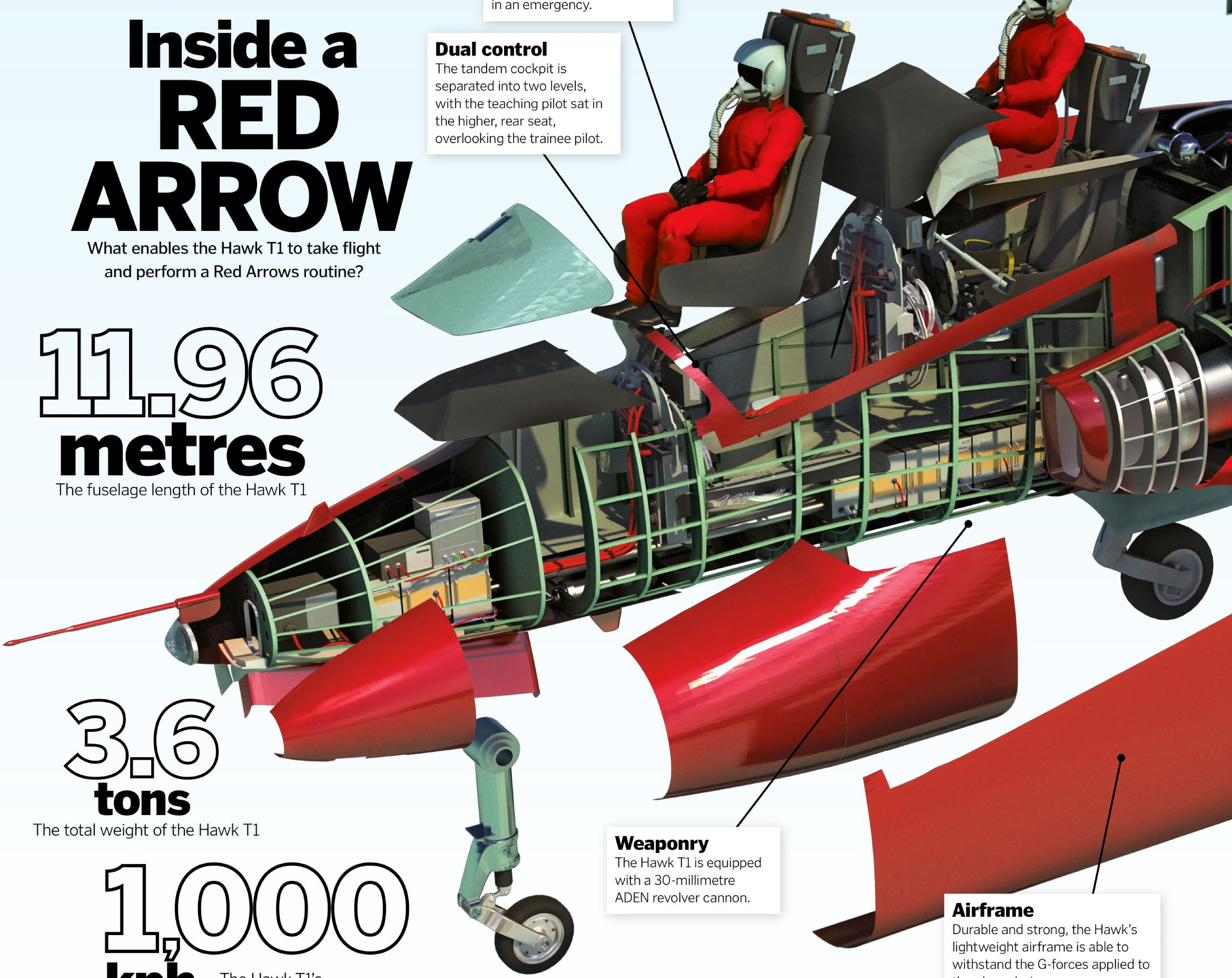
Inside a RED ARROW

What enables the Hawk T1 to take flight and perform a Red Arrows routine?

11.96 metres
The fuselage length of the Hawk T1

3.6 tons
The total weight of the Hawk T1

1,000 kph
The Hawk T1's maximum speed



Ejection seat
Each plane is fitted with rocket-assisted Martin-Baker Mk.10 ejection seats for use in an emergency.

Dual control
The tandem cockpit is separated into two levels, with the teaching pilot sat in the higher, rear seat, overlooking the trainee pilot.

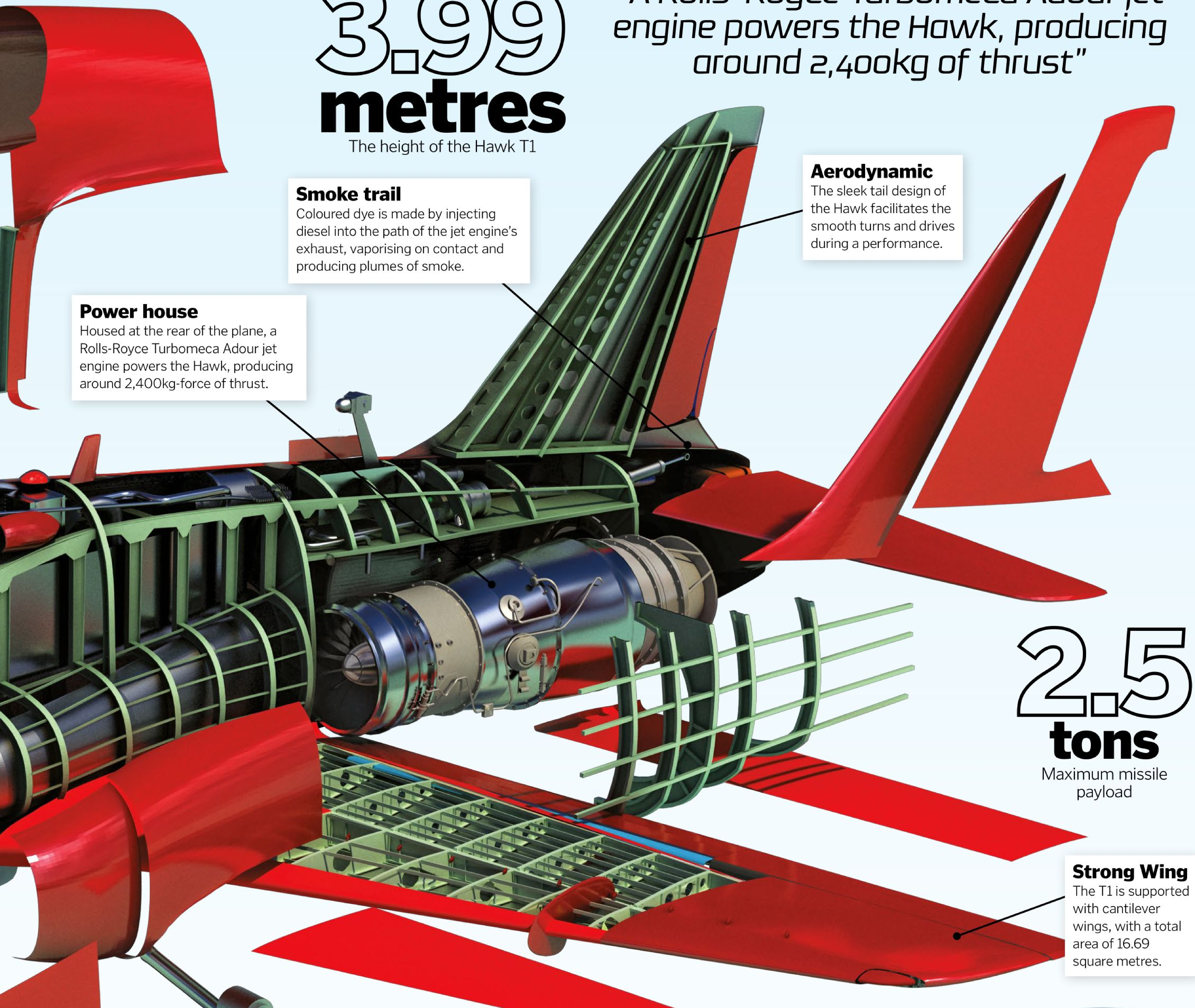
Weaponry
The Hawk T1 is equipped with a 30-millimetre ADEN revolver cannon.

Airframe
Durable and strong, the Hawk's lightweight airframe is able to withstand the G-forces applied to the plane during manoeuvres.

> *"A Rolls-Royce Turbomeca Adour jet engine powers the Hawk, producing around 2,400kg of thrust"*

3.99 metres

The height of the Hawk T1



Smoke trail
Coloured dye is made by injecting diesel into the path of the jet engine's exhaust, vaporising on contact and producing plumes of smoke.

Power house
Housed at the rear of the plane, a Rolls-Royce Turbomeca Adour jet engine powers the Hawk, producing around 2,400kg-force of thrust.

Aerodynamic
The sleek tail design of the Hawk facilitates the smooth turns and drives during a performance.

2.5 tons

Maximum missile payload

Strong Wing
The T1 is supported with cantilever wings, with a total area of 16.69 square metres.

Since 1979, the Hawk T1 has been the aircraft used in Red Arrows displays across the globe

ROYAL AIR FORCE

Used as a training aircraft, the cockpit can host two pilots

RESCUE FROM EITHER SIDE
DANGER

9.39 metres

The wingspan of the Hawk T1

FROM THE ARCHIVES
Originally published in 2017

Inside the I-PACE

Jaguar's first all-electric road car hits the road

Perhaps the most eagerly anticipated car of the century, Jaguar's first all-electric car combines sports car performance with supercar aesthetics. The I-PACE Concept crossover SUV is expected to speed from 0-100 kilometres per hour in just four seconds by harnessing the power of two efficient motors installed at the front and rear axles.

The absence of both an engine and a gear box means the car will be able to comfortably seat five in a spacious interior beneath an impressive full-length panoramic sunroof. The bold design and streamline silhouette creates a remarkably aerodynamic vehicle.

A rear spoiler will reduce lift and rear vents will channel air from the wheel arches into a smooth airflow behind the car to reduce drag, while the low centre of gravity makes for improved manoeuvrability and agility.

Electric cars provide a smoother driving experience. Ian Hoban, vehicle line director for Jaguar Land Rover, explains the benefits. "Electric motors provide immediate response with no lag, no gearshifts and no interruptions. Their superior torque delivery compared to internal combustion engines transforms the driving experience."

The I-PACE Concept is expected to have a range of over 500 kilometres on one charge, using a 50-kilowatt DC rapid charger that will take just two hours to reach full capacity. The car will come with two touchscreens in the centre of the dashboard, one to control information and entertainment functions and the other for the air conditioning and climate control.

With onboard Wi-Fi, the I-PACE is expected to be a blend of new technology and a polished aluminium and wood veneer interior. It is expected that the final production I-PACE will be seen by the end of this year, ready to go on sale in late 2018.

From Formula E to the I-PACE

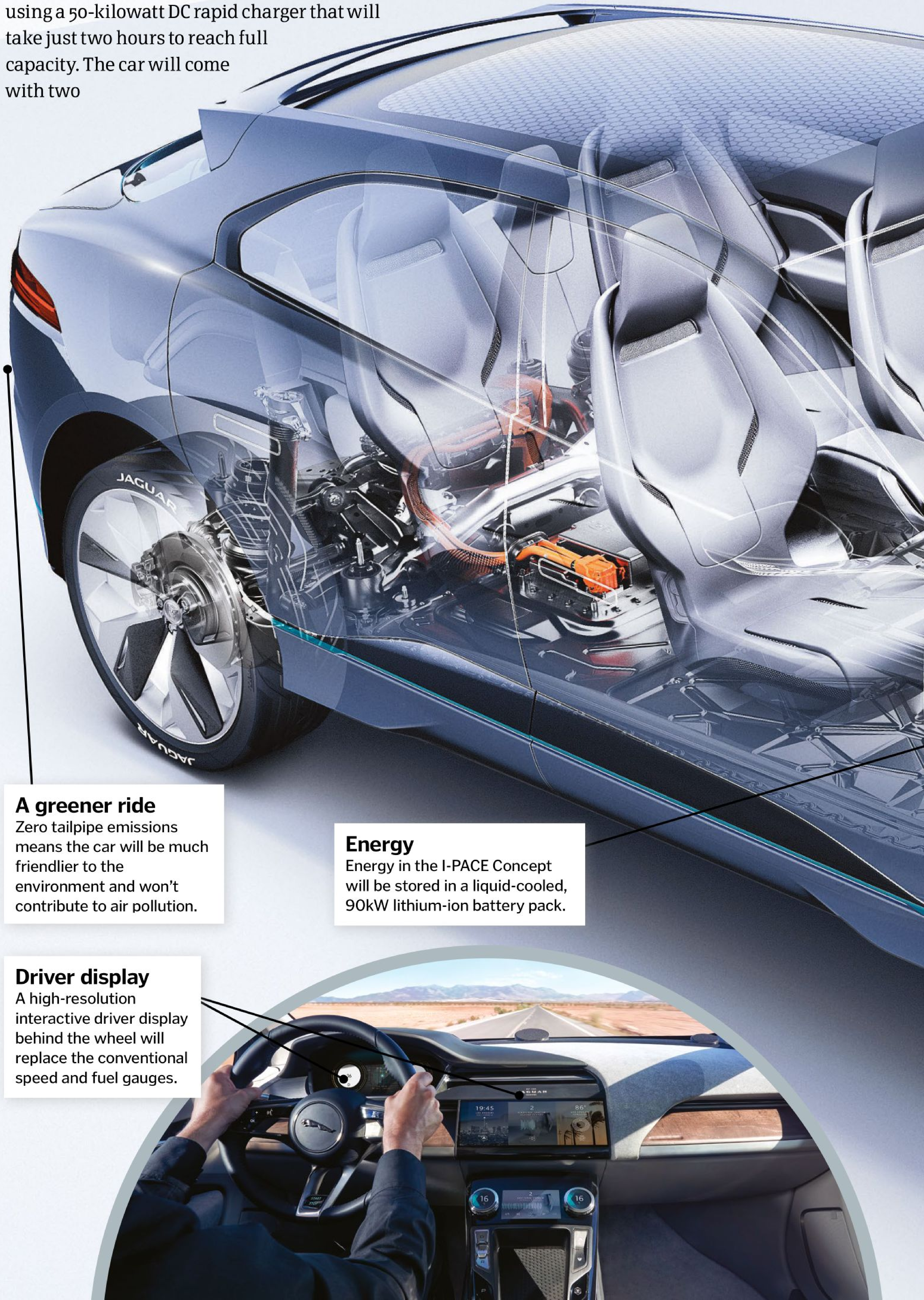
The Formula E Championship is a class of racing that uses only electric cars. It encourages innovation through engineering and design by keeping standardised chassis and battery systems but allowing teams to compete with their own design of electric motor, control unit and transmission. The championship is run on street circuits in the world's biggest cities and challenges the power and performance of electric sports cars.

The I-TYPE is Panasonic Jaguar Racing's all-electric Formula E race car. It accelerates from 0-100 kilometres per hour in just 2.9 seconds, and is able to recycle up to 150kW of it's energy when it brakes to further extend its range.

The technical expertise and superb results from driving the Formula E have now been transferred over from the I-TYPE to the I-PACE. The new I-PACE will base its thermal management and motor location on its sports car predecessor as it continues to refine transferring power to the road efficiently.

JAGUAR
Panasonic
JAGUAR
JAGUAR

Jaguar Racing's all-electric Formula E race car is the ultimate balance of power and efficiency



A greener ride
Zero tailpipe emissions means the car will be much friendlier to the environment and won't contribute to air pollution.

Energy
Energy in the I-PACE Concept will be stored in a liquid-cooled, 90kW lithium-ion battery pack.

Driver display
A high-resolution interactive driver display behind the wheel will replace the conventional speed and fuel gauges.

> *"Electric vehicles are inevitable – Jaguar will make them desirable. Zero-emission cars are here to stay, and the I-PACE Concept is at the cutting edge of the electric vehicle revolution"*
>
> Ian Hoban, vehicle line director, Jaguar Land Rover

500km

The distance the I-PACE will go on just one charge

90 minutes

The amount of time it will take for the car to charge to 80 per cent capacity.

4 seconds

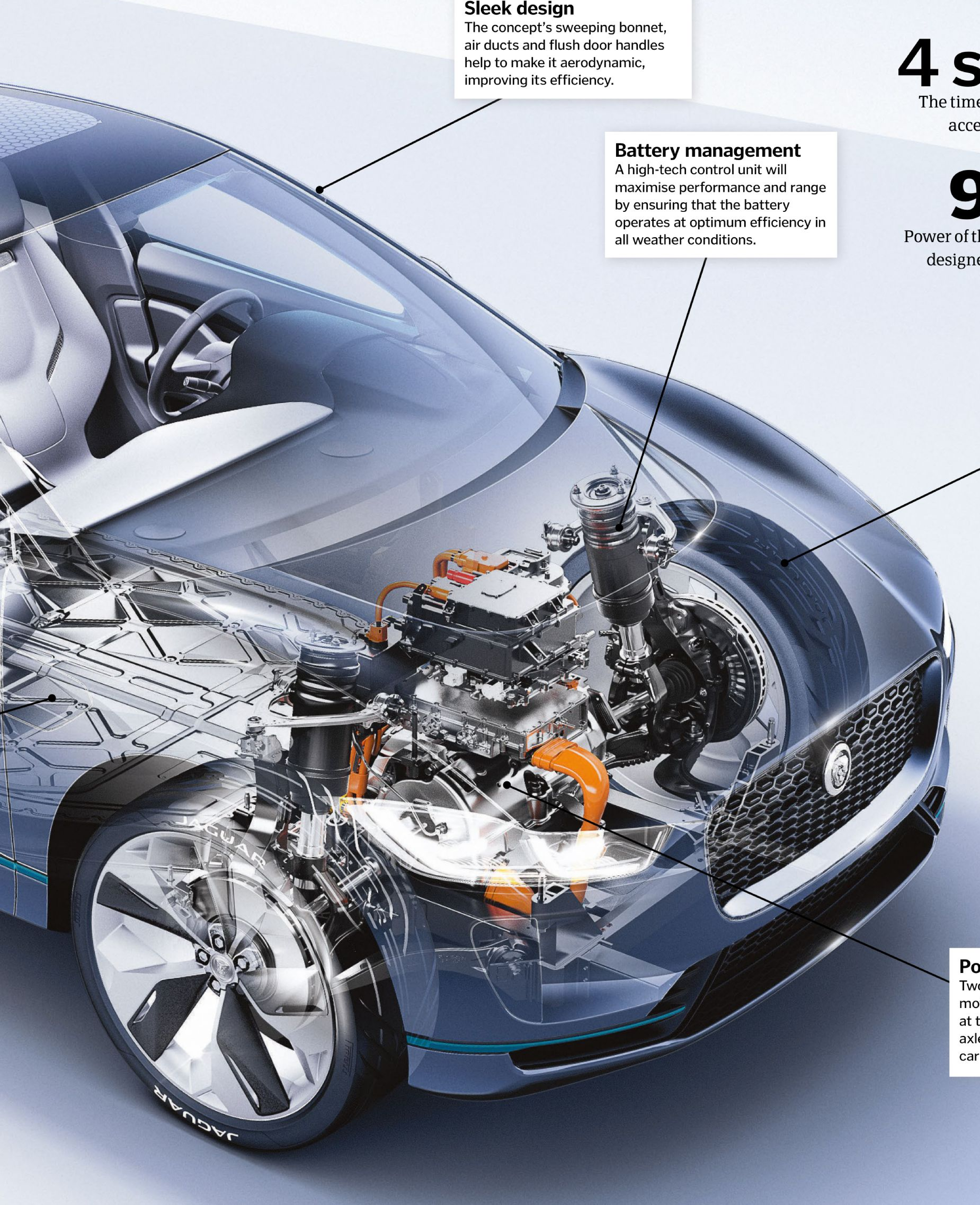
The time it will take for the SUV to accelerate from 0-100kph.

90kW

Power of the lithium-ion battery pack designed by Jaguar Land Rover.

Jaguar I-PACE technology

We go under the bonnet of the next big star on the electric car scene



Sleek design
The concept's sweeping bonnet, air ducts and flush door handles help to make it aerodynamic, improving its efficiency.

Battery management
A high-tech control unit will maximise performance and range by ensuring that the battery operates at optimum efficiency in all weather conditions.

Four-wheel drive
The I-PACE will have four-wheel drive capability for all-weather driving on any surface.

Power
Two efficient magnet motors will be installed at the front and rear axles to provide sports car acceleration.

©Jaguar Land Rover

Inside the RRS Sir David Attenborough

The RRS Sir David Attenborough is built to withstand harsh environments

One of the world's most advanced research vessels takes to the seas

In July 2019 one of the most sophisticated floating research platforms ever built took to the sea.

Packed with state-of-the-art labs, testing facilities, research equipment and unmanned drones, the RRS Sir David Attenborough has been designed to uncover the mysteries of our polar regions, helping scientists research the oceans, atmosphere, sea beds and ice located at some of the most remote and inhospitable parts of the world.

Commissioned by the Natural Environment Research Council (NERC) in 2014, the vessel is operated by the British Antarctic Survey, replacing its two existing ships – the RRS Ernest Shackleton and the RRS James Clark Ross, which are nearing the end of their lives in polar exploration.

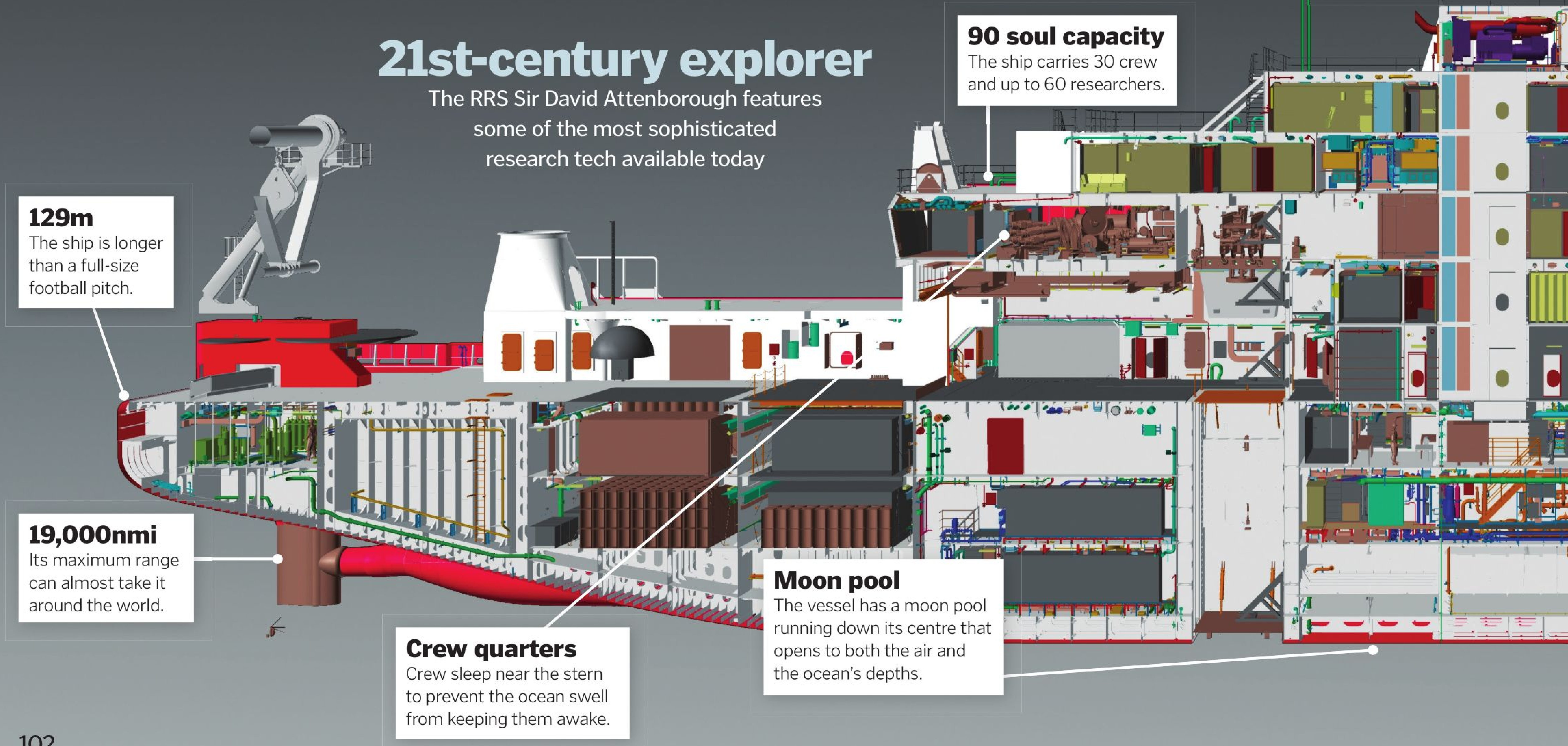
Named after legendary naturalist and broadcaster Sir David Attenborough, the ship will operate throughout the year, spending the northern hemisphere's summer in the Arctic, then sailing south for the southern summer, carrying out research and shipping supplies and staff to the British Antarctic Survey's bases and research outposts.

Due to its nature as a polar vessel, the ship has been designed to operate in extreme environments, with the ability to break through ice up to one metre thick. It can also carry enough fuel and food to remain at sea for up to 60 days at a time without needing to take on fresh supplies from support ships.

But it's in the scientific field that the ship is truly groundbreaking. It's equipped with both submersible and flying automated and remote-controlled drones. It also contains a 'moon pool' – a shaft running right through its middle, open to the sky at one end and the ocean depths at the other, so the remote craft can be launched and recovered.

21st-century explorer

The RRS Sir David Attenborough features some of the most sophisticated research tech available today



Science vessel
The ship is bristling with sensors to support its scientific mission aid the complex polar navigation.

90 soul capacity
The ship carries 30 crew and up to 60 researchers.

129m
The ship is longer than a full-size football pitch.

19,000nmi
Its maximum range can almost take it around the world.

Crew quarters
Crew sleep near the stern to prevent the ocean swell from keeping them awake.

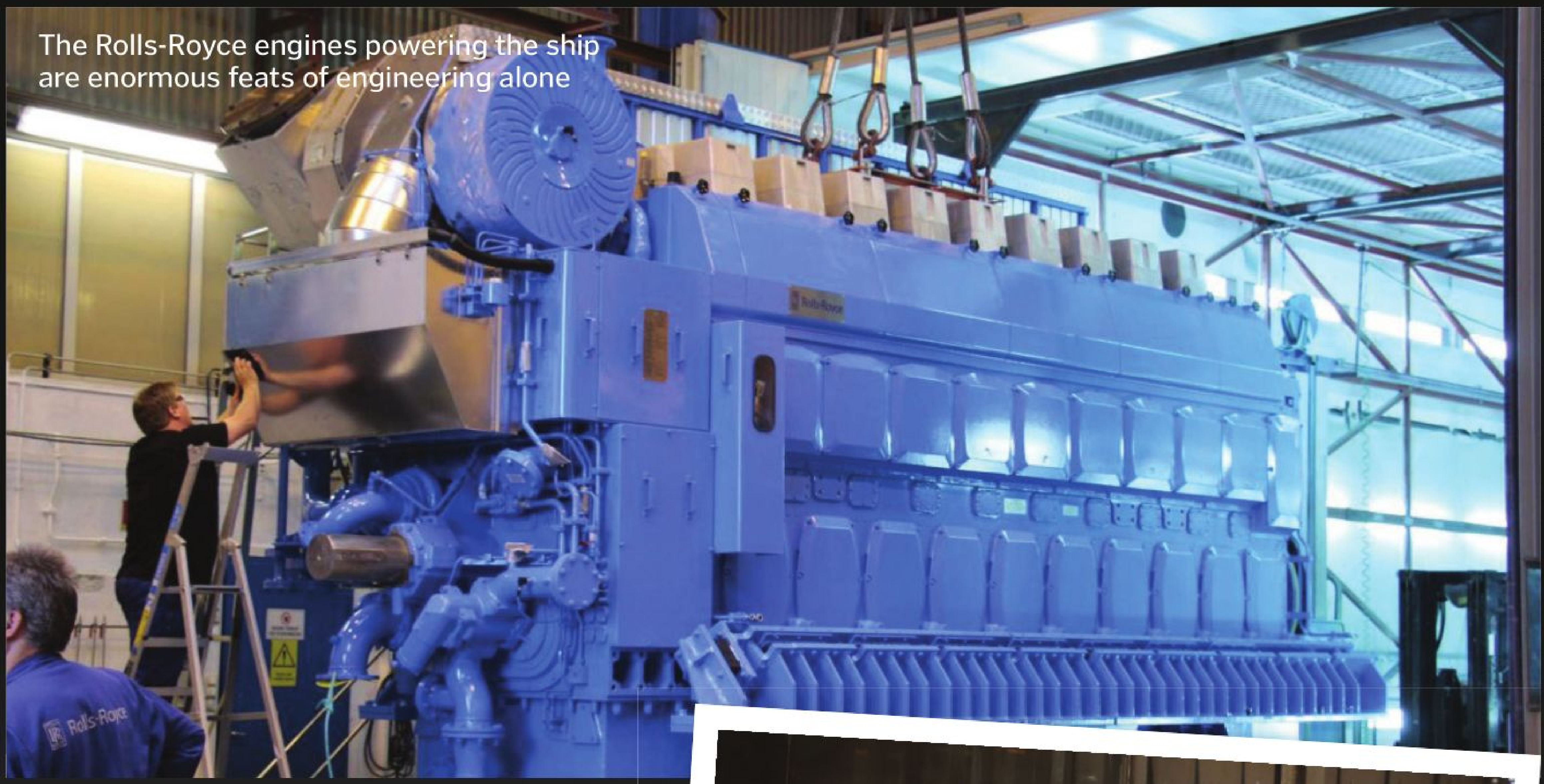
Moon pool
The vessel has a moon pool running down its centre that opens to both the air and the ocean's depths.

Environmentally friendly visitor

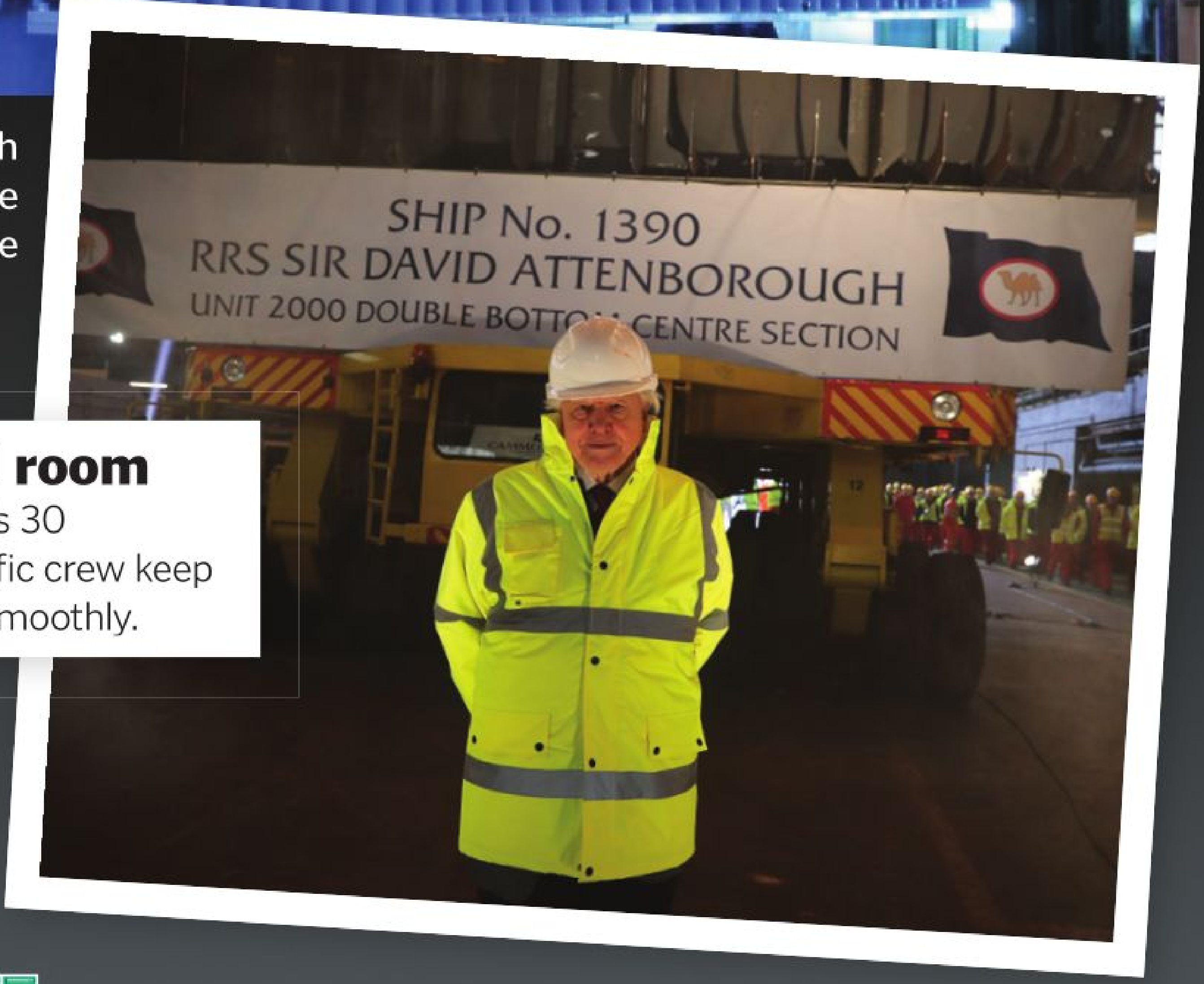
Of course, for a ship that's tasked with keeping an eye on the damage being done to our polar regions, the last thing its designers want is for it to become part of the problem.

To this end, the vessel has been designed with four main Rolls-Royce engines that operate on ultra-low-sulphur fuel, limiting its sulphur dioxide emissions.

The ship is also fitted with an oily bilge water separator that consists of a high-speed centrifuge to reduce the oil content of the bilge water discharged. Biodegradable oils have also been used wherever possible. It can also store its own sewage for up to 45 days when it's in parts of the world where even treated sewage discharge isn't allowed.


The Rolls-Royce engines powering the ship are enormous feats of engineering alone

© ROLLS-ROYCE


Sir David Attenborough officially launches the ship with his name

SHIP No. 1390
RRS SIR DAVID ATTENBOROUGH
UNIT 2000 DOUBLE BOTTOM CENTRE SECTION

Introducing Boaty McBoatface

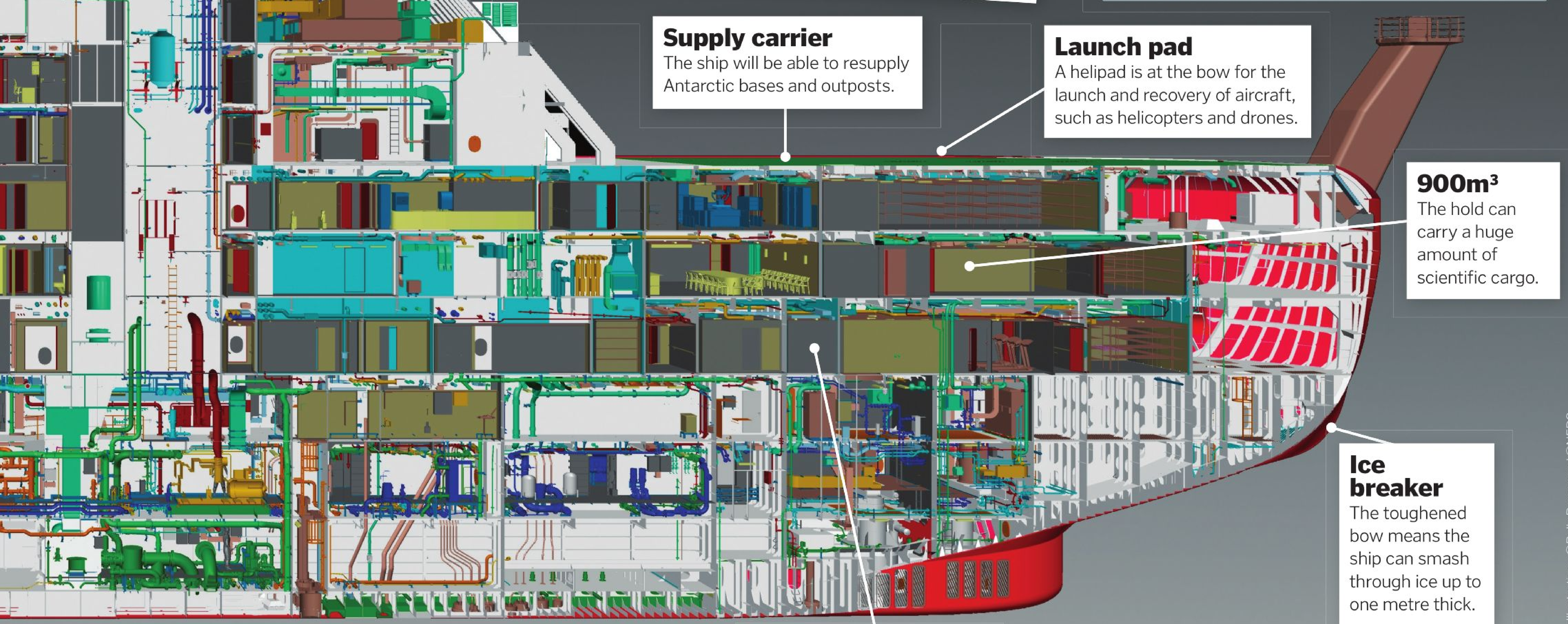
As a brand new research vessel designed for 2019 and beyond, the RRS Sir David Attenborough has been designed to act as a mother ship to a range of highly sophisticated remote and automated drones. One of these automated vessels is called Boaty McBoatface.

At just over 3.6 metres long, it's an 'autosub', an automated submersible that can travel for 2,000 kilometres on its own at depths of up to 6,000 metres.

One of three such marine robots carried by the mother ship, its ability to travel under ice for prolonged periods will enable it and its sister drones to explore up to 95 per cent of the ocean.

The autosub got its decidedly wacky name after the UK's Natural Environment Research Council conducted a poll to ask the public to name the ship itself (that would eventually be named the RRS Sir David Attenborough). Boaty McBoatface topped the results after it was suggested by a former BBC Radio Jersey presenter as a joke that backfired.

Boaty McBoatface is an unmanned submersible designed to explore beneath the ice



Control room
The vessel's 30 non-scientific crew keep it running smoothly.

Supply carrier
The ship will be able to resupply Antarctic bases and outposts.

Launch pad
A helipad is at the bow for the launch and recovery of aircraft, such as helicopters and drones.

900m³
The hold can carry a huge amount of scientific cargo.

Ice breaker
The toughened bow means the ship can smash through ice up to one metre thick.

On-board stores
It can remain at sea for up to two months unsupplied.

© Getty; Illustrations @Rolls Royce and @NERC

18+

WHAT IS
AVAXHOME?

AVAXHOME -

the biggest Internet portal, providing you various content: brand new books, trending movies, fresh magazines, hot games, recent software, latest music releases.

Unlimited satisfaction one low price
Cheap constant access to piping hot media
Protect your downloadings from Big brother
Safer, than torrent-trackers

18 years of seamless operation and our users' satisfaction

All languages
Brand new content
One site

AVXLIVE.ICU

AvaxHome - Your End Place

We have everything for all of your needs. Just open https://avxlive.icu

A jack of all trades, the Humvee can be configured to perform many roles

© AM General

A snorkel and raised exhaust make the Humvee a great amphibious vehicle

The Humvee

The high-mobility multipurpose wheeled vehicle (HMMWV) roars off the production line ready for action

Designed to replace several outdated American military vehicles, the high-mobility multipurpose wheeled vehicle, or Humvee, has been in production since 1985. Originally intended as a light utility vehicle, there have been more than 20 variants of this highly customisable, modular platform. Serving over 40 nations, around 200,000 Humvees have been built to date. Able to carry and deploy almost anything, from fully armed troops to anti-aircraft missiles, the Humvee is an open-topped scout vehicle, an armoured personnel carrier, ambulance, a TOW missile launcher, a communication centre, a heavy machine gun platform and whatever else the situation requires.

The latest models are unrivalled in their off-road capability, and are based around a 6.5-litre (1.7-gallon) V8 Turbo diesel engine which produces 142 kilowatts (190 brake horsepower) and 515 Newtons per metre (380 pounds force per foot) of torque. This power is sent to all four wheels through an electronically controlled four-speed automatic gearbox, using a series of differentials. The drivetrain is rather unconventional as the wheels themselves contain portal-geared hubs, which not only double the torque generated, but due to the offset driveshaft inputs, enable the vehicle's ground clearance to be significantly higher than a regular centre axle would allow. This innovative drivetrain, coupled with independent suspension and 94-centimetre (37-inch) tyres, allow the Humvee to travel at 113 kilometres (70 miles) per hour or to climb slopes of 60 per cent – though some Humvees have been seen to climb near-vertical walls! The internal environment is fully air conditioned, while a deep-water fording kit allows the vehicle to cross rivers almost completely submerged. These capabilities, combined with design features such as the sturdy chassis, corrosion resistance plus high commonality and interchangeable parts, enable the Humvee to be flexible, dependable and rugged even in the harshest of environments.

The turret can be fitted with weapons for all kinds of combat situation

© AM General

Armour options

Since the Humvee was introduced, soldiers have demanded increasingly more protection from it. Early versions had fabric doors and no roof, but the demands of Somalia, Iraq and Afghanistan demonstrated the need for improved armour. Many improvised solutions have been tried in the field in recent years, including sandbags and welding scrap metal to the chassis. However, heavily armoured versions are now available from the factory, as are retrofit kits, which include under-body plates, heavy doors, armoured seats, weapon shields and many other additions. The latest iterations offer the crew protection from assault rifle bullets, some air-burst artillery, and up to 5.4 kilograms (12 pounds) of explosives, thanks to thick steel armour, energy-absorbing coatings and mounting, and reinforced glass. All of this comes at a price, though, with many Humvees carrying 907-1,814 kilograms (2,000-4,000 pounds) of armour, which can only be taken in place of cargo and equipment. Work is underway to make the Humvee more resistant to buried explosives, as the large flat floor is not effective against these.

HEAD 2 HEAD
BATTLEFIELD VEHICLES

1. MEAN

Willys Jeep
Released at the end of WWII in 1945, the civilian version of the military vehicle was updated regularly and is still on sale to this day.

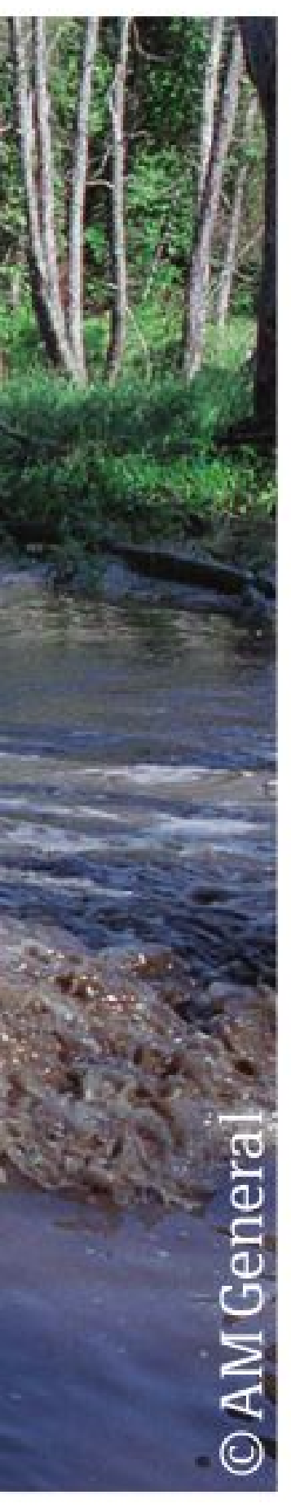
2. MEANER

Land Rover Defender
Still used by the British armed forces today, the Land Rover Defender is based on the original 1948 Land Rover.

3. MEANEST

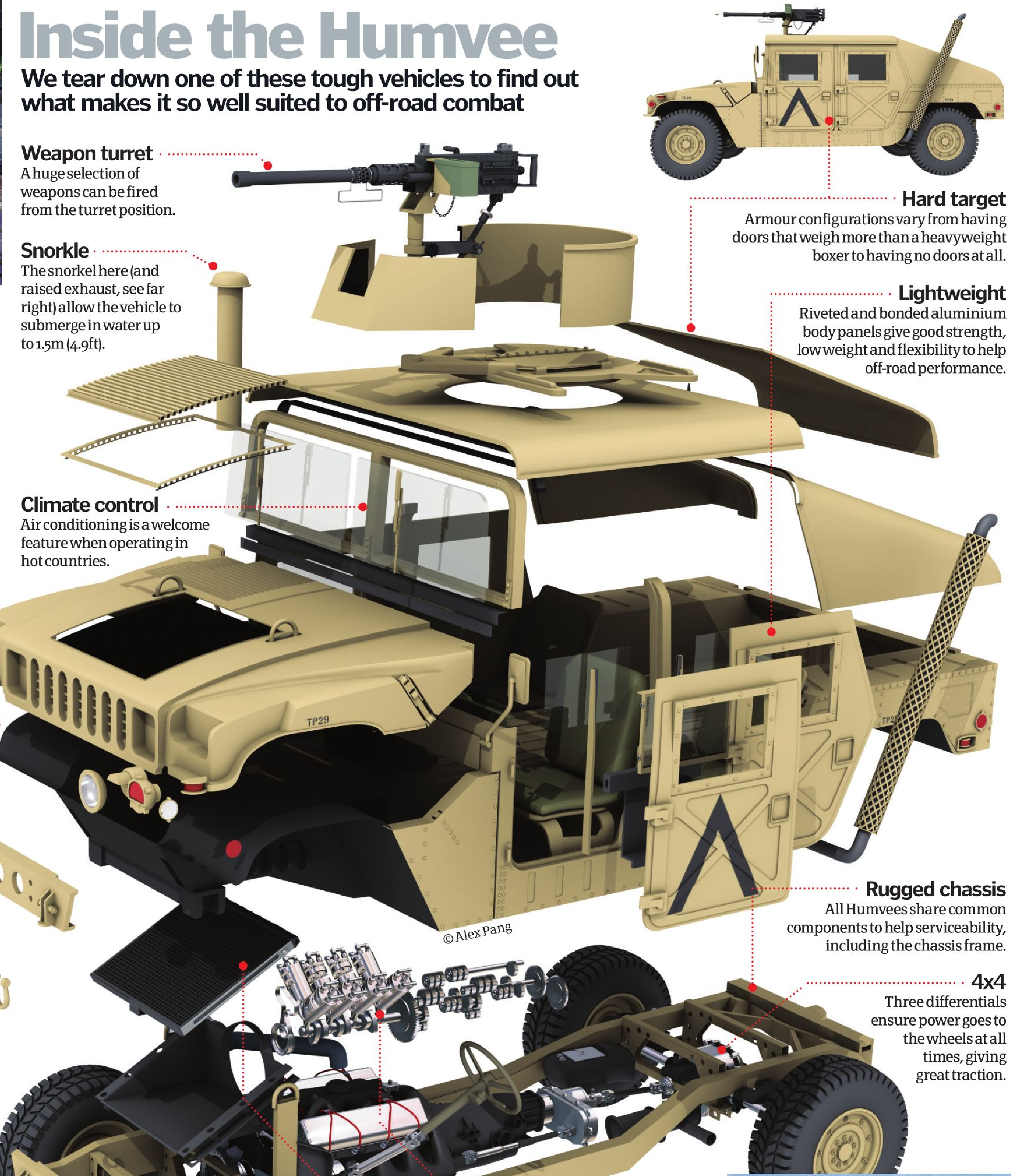
Hummer H1
Also built in the HMMWV factory, the main difference between this beast of a civilian truck and the military version is the colour.

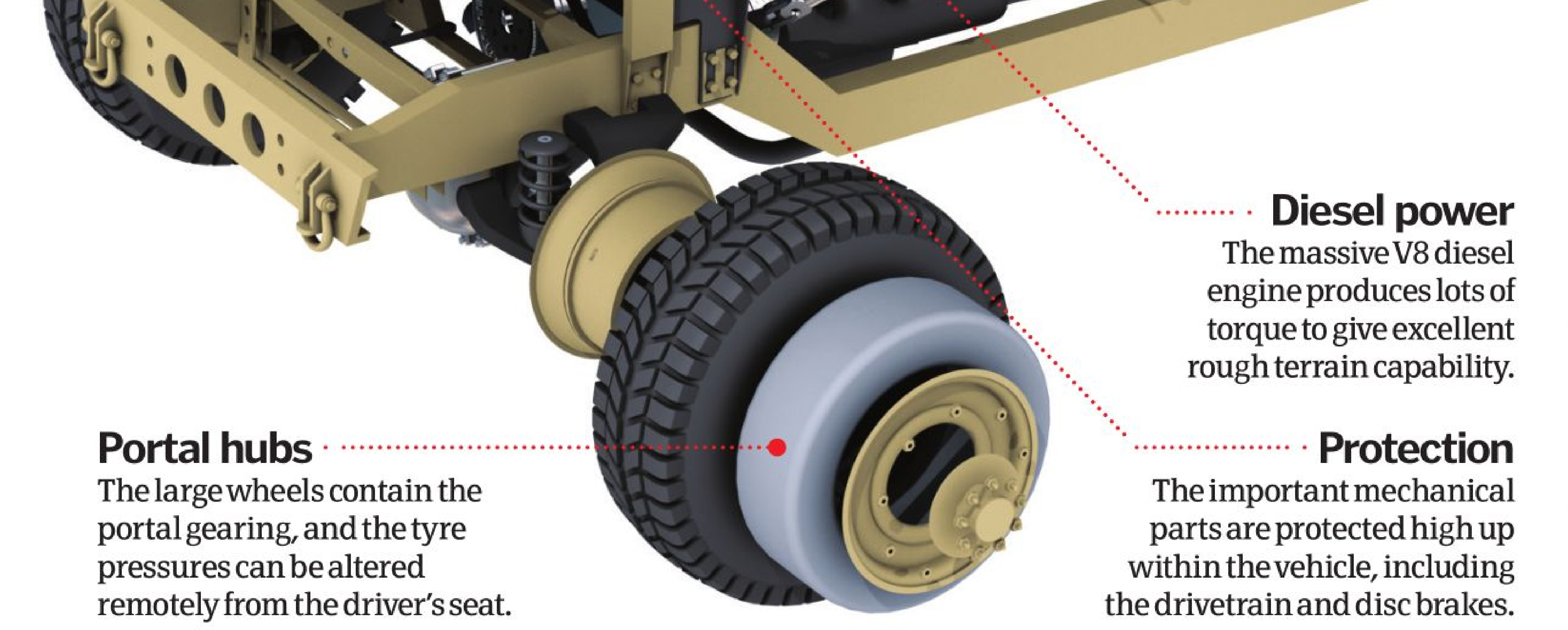
DID YOU KNOW? Arnold Schwarzenegger was so impressed with the Humvee, he insisted AM General sold him one


© AM General

Inside the Humvee

We tear down one of these tough vehicles to find out what makes it so well suited to off-road combat





Weapon turret
A huge selection of weapons can be fired from the turret position.

Snorkle
The snorkel here (and raised exhaust, see far right) allow the vehicle to submerge in water up to 1.5m (4.9ft).

Climate control
Air conditioning is a welcome feature when operating in hot countries.

Hard target
Armour configurations vary from having doors that weigh more than a heavyweight boxer to having no doors at all.

Lightweight
Riveted and bonded aluminium body panels give good strength, low weight and flexibility to help off-road performance.

Rugged chassis
All Humvees share common components to help serviceability, including the chassis frame.

4x4
Three differentials ensure power goes to the wheels at all times, giving great traction.

Diesel power
The massive V8 diesel engine produces lots of torque to give excellent rough terrain capability.

Protection
The important mechanical parts are protected high up within the vehicle, including the drivetrain and disc brakes.

Portal hubs
The large wheels contain the portal gearing, and the tyre pressures can be altered remotely from the driver's seat.

© Alex Pang

Packing a punch

There was always a requirement to arm the Humvee to provide fire support and self-defence, but the variety of weapons it can carry is astonishing. Starting with a choice of general-purpose machine guns, most weapons can be fired manually or fitted to the remotely operated CROWS turret system. The most common weapon choice is the legendary M2 Browning .50 Calibre. However, should there be a need to raze everything in sight to the ground, the gunner can unleash 100 shots per second using the awesome M134 minigun. For even bigger bangs, the 40-millimetre (1.6-inch) grenade machine gun can launch 60 high-explosive grenades per minute. Should an enemy bring a tank to the fight, the Humvee can launch the TOW anti-armour missile from 3.8 kilometres (2.3 miles) away, or in situations requiring a little bit of overkill, the Humvee is designed to tow a Howitzer cannon. The ultimate version, however, has to be the Boeing-developed Avenger, which carries up to eight stinger anti-aircraft missiles, with proposals for additional weapons including a one-kilowatt laser.

For long-distance enemies more heavy-duty weapons can be deployed

Snow groomers

Discover how these machines help keep the slopes ski-ready

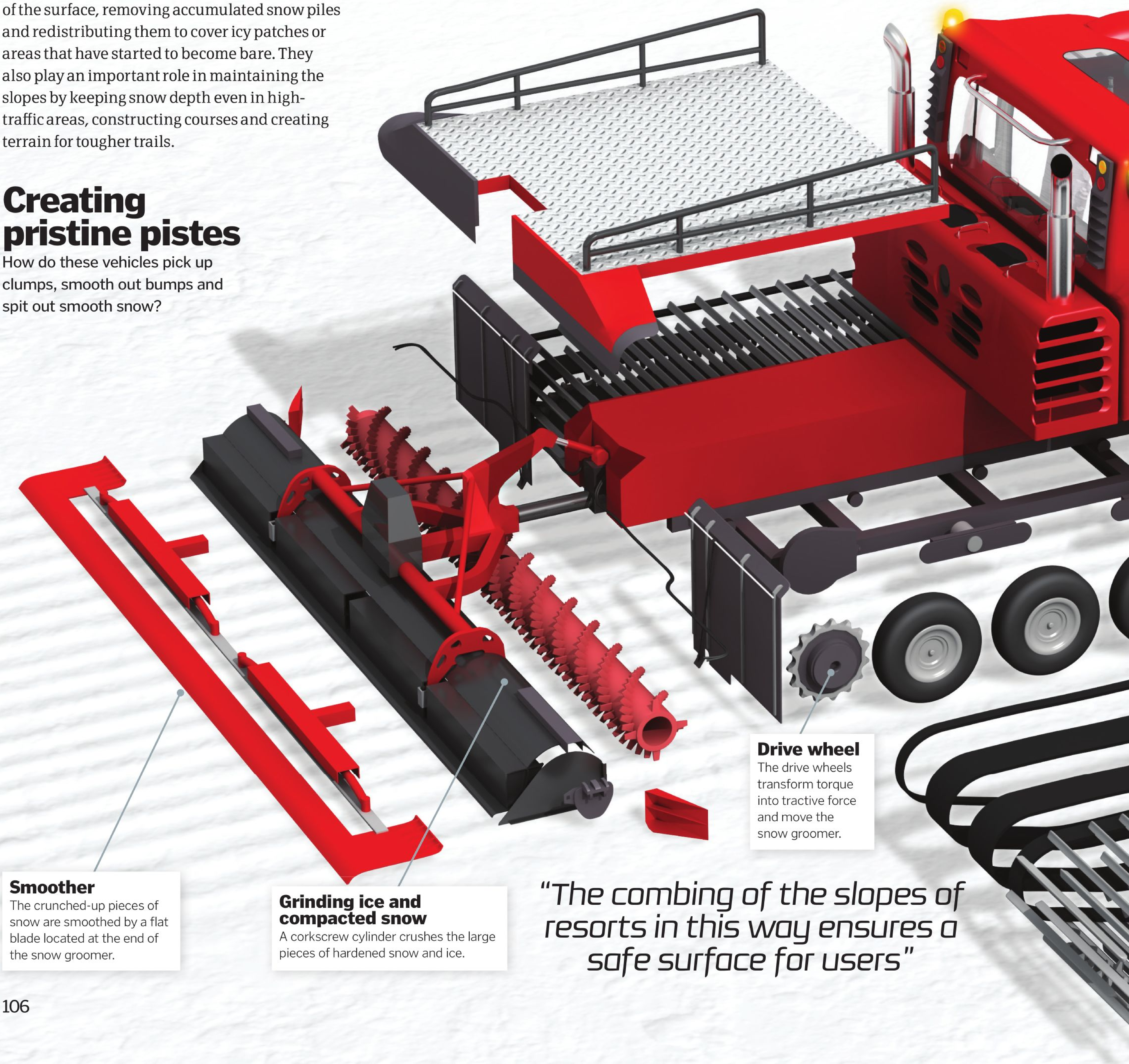
After snowboarders and skiers have packed up their kit and started to head home, it's time for the staff of a snow sport resort to start their daily maintenance. One of the most important tasks is snow grooming; the smoothing of the pistes that is diligently carried out every night. To do this a tractor or truck is normally used to carry specialist towing equipment. They operate by moving, flattening or compacting the snow to improve the condition of the surface, removing accumulated snow piles and redistributing them to cover icy patches or areas that have started to become bare. They also play an important role in maintaining the slopes by keeping snow depth even in high-traffic areas, constructing courses and creating terrain for tougher trails.

The machine runs on two large tracks made from rubber and steel that disperse the weight of the vehicle evenly across the surface. Fitted to the rear is a power tiller that churns the snow before a heavy comb or smoother pulls across the surface. This tiller is responsible for leaving behind the distinctive striped patterns of a groomed slope.

When you see the pistes before hundreds of skiers and snowboarders have taken to the slopes, you will notice lots of thin, uniform lines in the snow. These have been left behind by a snow groomer after the small cogs inside the vehicle have broken up the surface. The combing of the slopes of resorts in this way ensures a safe surface for users every day of the skiing season.

Creating pristine pistes

How do these vehicles pick up clumps, smooth out bumps and spit out smooth snow?



Drive wheel
The drive wheels transform torque into tractive force and move the snow groomer.

Smoother
The crunched-up pieces of snow are smoothed by a flat blade located at the end of the snow groomer.

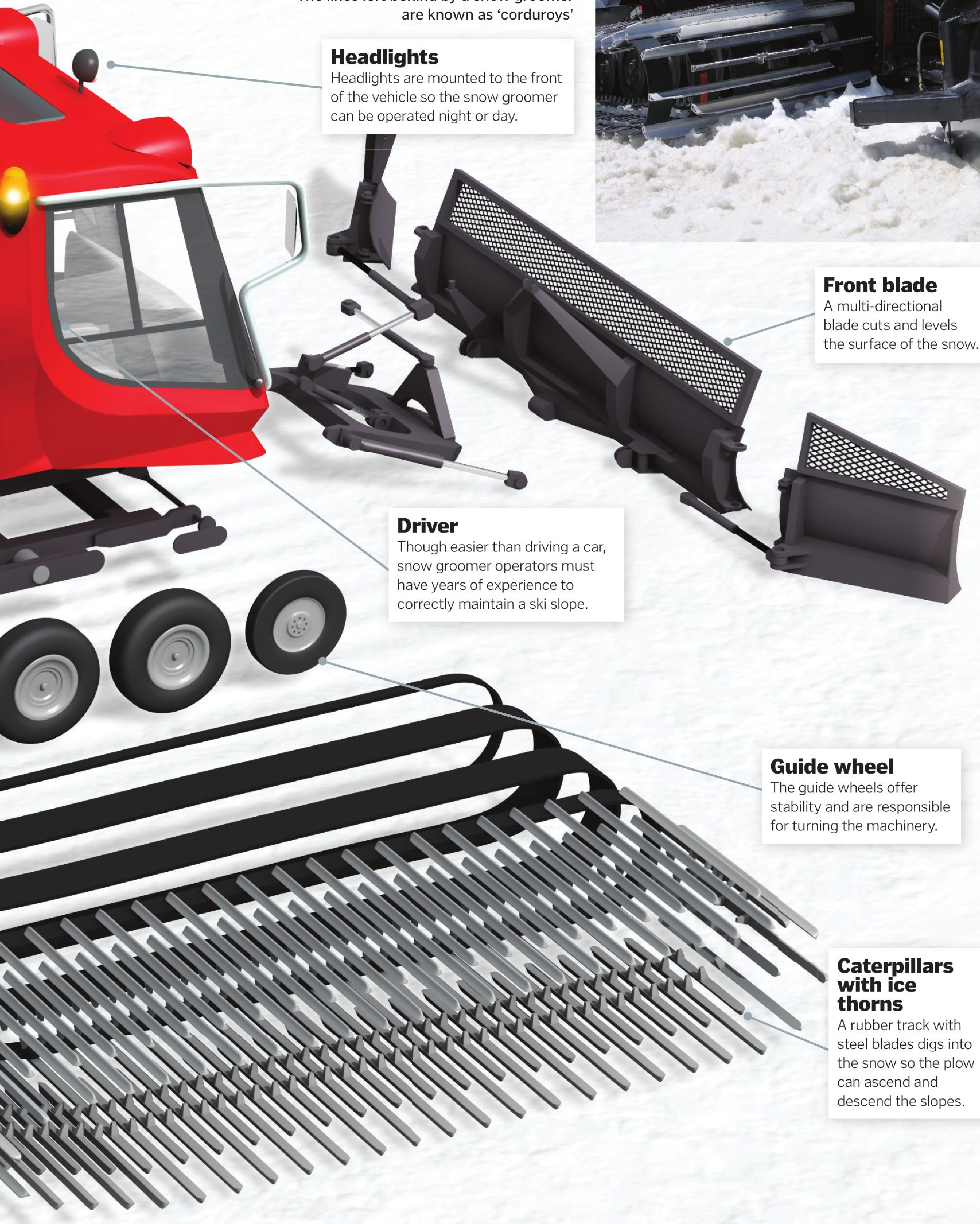
Grinding ice and compacted snow
A corkscrew cylinder crushes the large pieces of hardened snow and ice.

> "The combing of the slopes of resorts in this way ensures a safe surface for users"

DID YOU KNOW? *The first snow groomers were agricultural rollers pulled by a small tractor to compact the surface*

The lines left behind by a snow groomer are known as 'corduroys'

The steel blades on the caterpillar track of snow groomers help the vehicle climb by digging into the snow and providing grip



Headlights
Headlights are mounted to the front of the vehicle so the snow groomer can be operated night or day.

Front blade
A multi-directional blade cuts and levels the surface of the snow.

Driver
Though easier than driving a car, snow groomer operators must have years of experience to correctly maintain a ski slope.

Guide wheel
The guide wheels offer stability and are responsible for turning the machinery.

Caterpillars with ice thorns
A rubber track with steel blades digs into the snow so the plow can ascend and descend the slopes.

5 FACTS ABOUT SNOW GROOMERS

1 Steep slope groomers
When the gradient of a ski slope is high, snow groomers are attached to a winch and hauled to the top before being slowly lowered in reverse to smooth the snow.

2 Snow farming
Snow farming is a method of strategically manipulating snow coverage (usually by using obstacles or equipment) to create piles that can be redistributed by snow groomers.

3 Piste basher
Snow groomers are also known as snow smoothers, snowcats, or in some places they are informally known as 'piste bashers'.

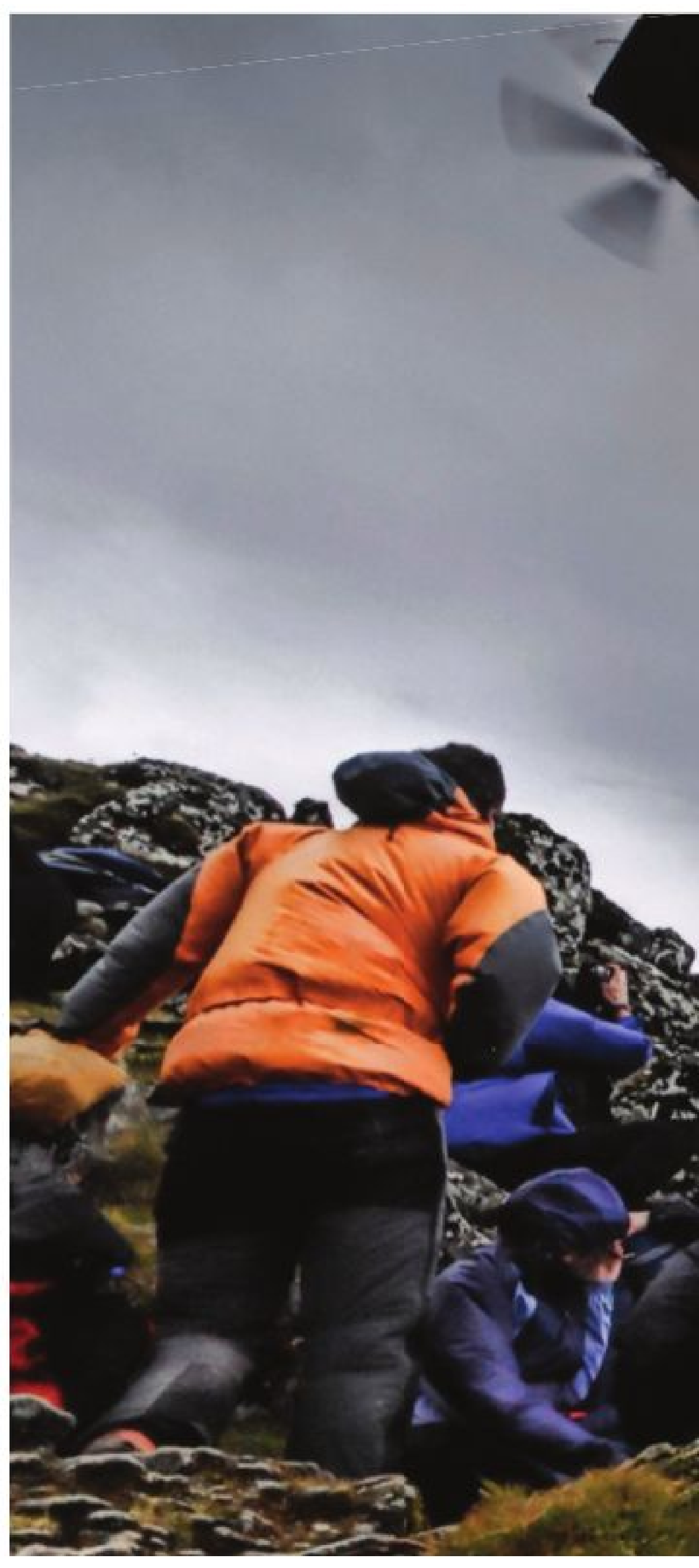
4 Other purposes
Because snow groomers are lightweight they are also used in agriculture and for work on peat bogs and biogas sites.

5 The first snow groomer
The first patented snow groomer was invented by Stephen Bradley in March 1957 for grading and packing snow.

© Getty; Illustration by Adrian Mann

How helicopters fly

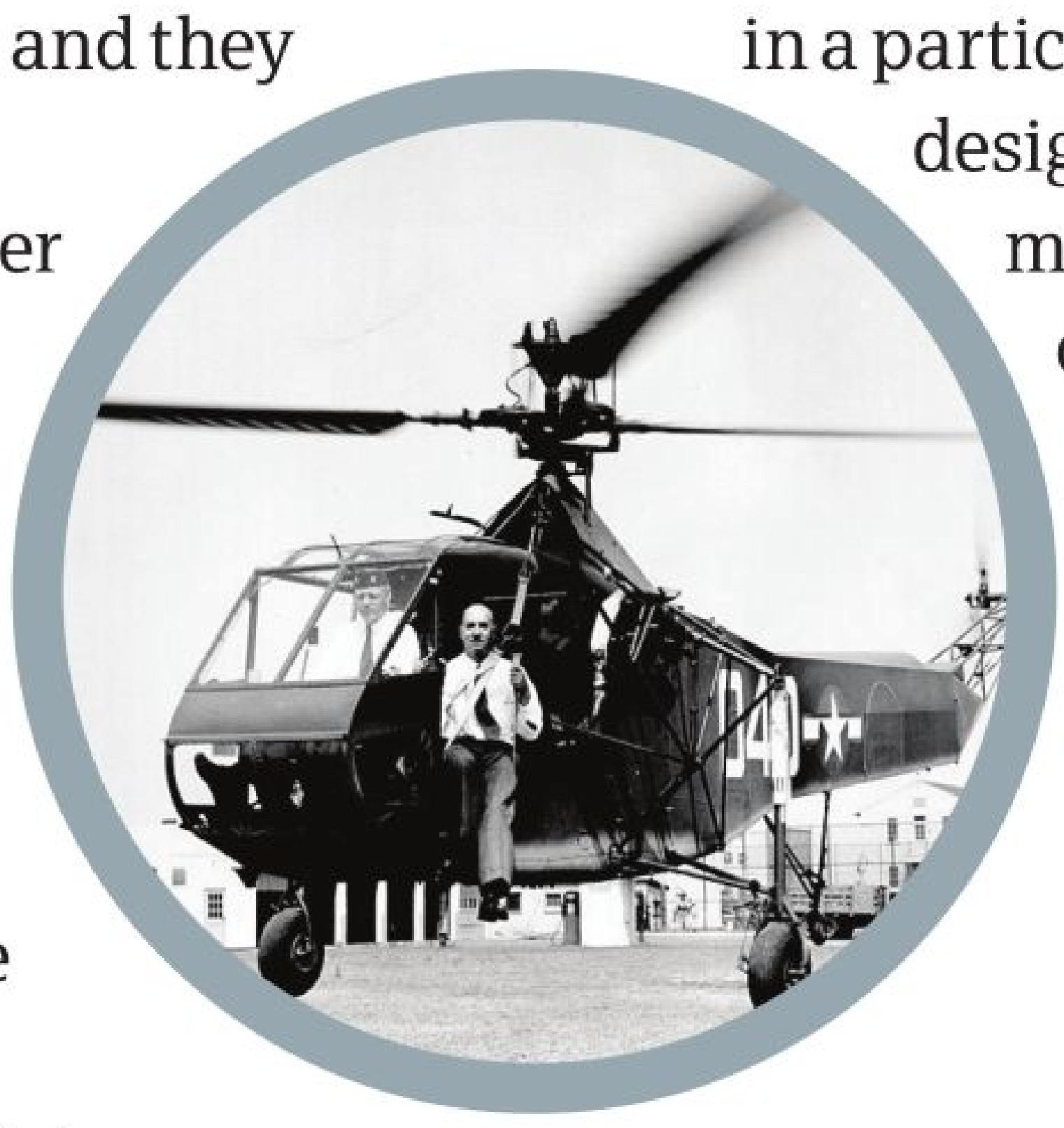
Discover the science behind helicopter flight and what makes them our most inventive flying machine



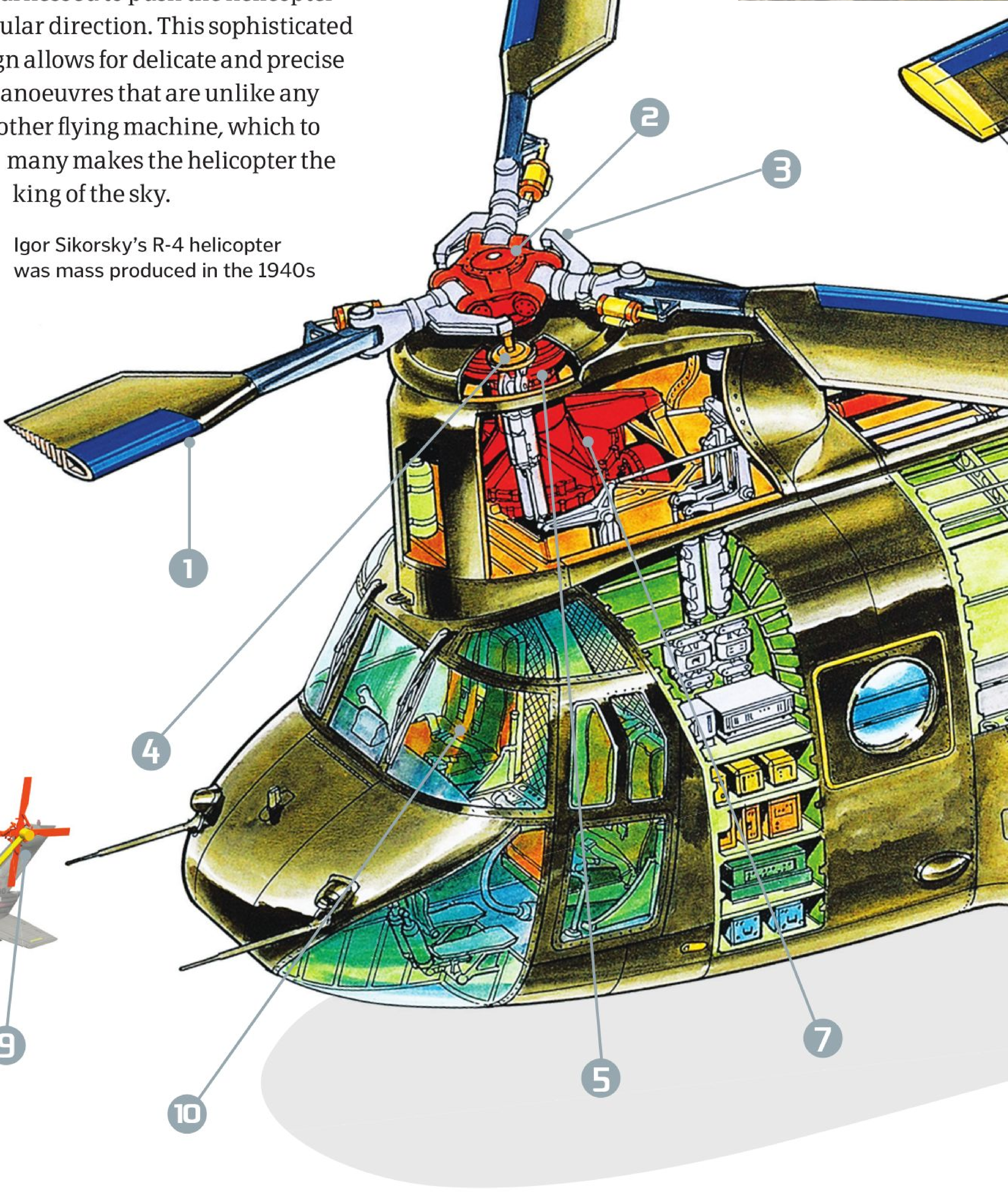
Helicopters are incredible vehicles. They're able to take off and land just about anywhere, and once in the air they can hover, swivel, yaw, ascend, descend and zoom off in any direction with ease. This amazing airborne control makes them perfectly suited to rescuing people at sea and on land, fighting fires and performing combat manoeuvres. From the ambulance service to the air force to the transport industry, helicopters have become a major asset by reaching the places that no other machine can, and they do it in style.

The concept of a helicopter is over 1,500 years old, and somewhat bizarrely finds its origin as a Chinese toy. Children were instructed to attach feathers to the end of a stick and spin it quickly, which would create enough lift to raise the toy into the air. Leonardo da Vinci would later famously theorise on his own 'aerial screw' during the Italian Renaissance, but it was an 18th-century Russian engineer by the name of Mikhail Lomonosov who would actually assemble a working, spring-powered model of coaxial helicopter blades. About 180 years after him a fellow countryman by the name of Igor Sikorsky would graduate from models of his own to the real thing by patenting and flying in his very own flying machine. Sikorsky's pioneering R-4 would go on to become the world's first mass-produced helicopter.

The genius of helicopter design relies on manipulating aerodynamic forces to achieve change in orientation, altitude and speed. By altering the position, relative angles and spin rate of helicopter blades, forces such as lift and torque can be harnessed to push the helicopter in a particular direction. This sophisticated design allows for delicate and precise manoeuvres that are unlike any other flying machine, which to many makes the helicopter the king of the sky.

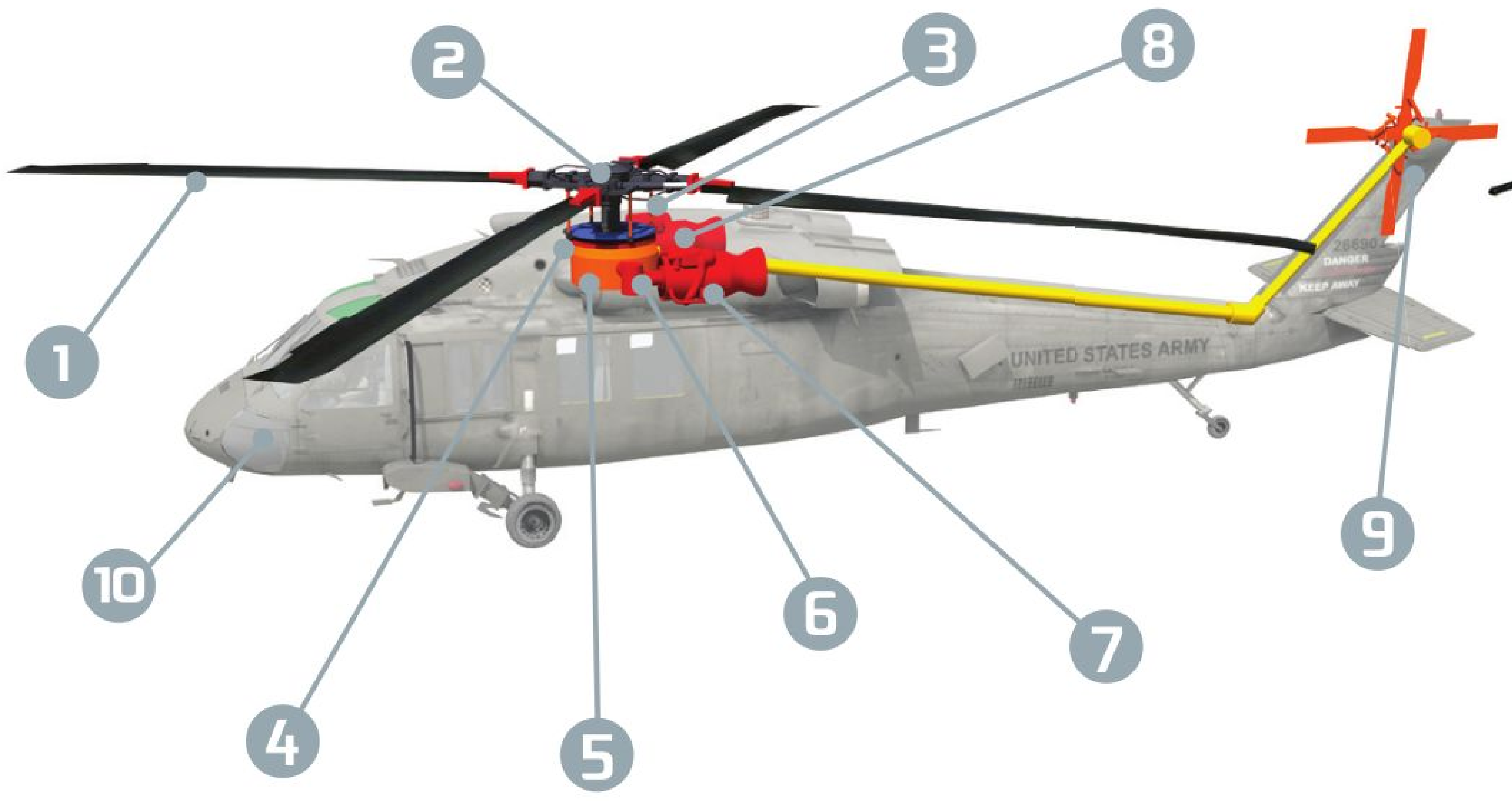


Igor Sikorsky's R-4 helicopter was mass produced in the 1940s



To the skies

The mechanics that make the helicopter the most versatile machine in the air



1 Main rotor blade Like an airplane, these blades are shaped as an aerofoil, which narrow to one side and create lift when rapidly rotated.

2 Rotating hinge Each blade is independently affixed to the rotating mast by a feathering hinge, which allows the blade to swivel.

3 Control rods Pitch links connect each blade to the swash plate below. When tilted, the raised section of the plate forces the rod to swivel its blade, increasing its pitch.

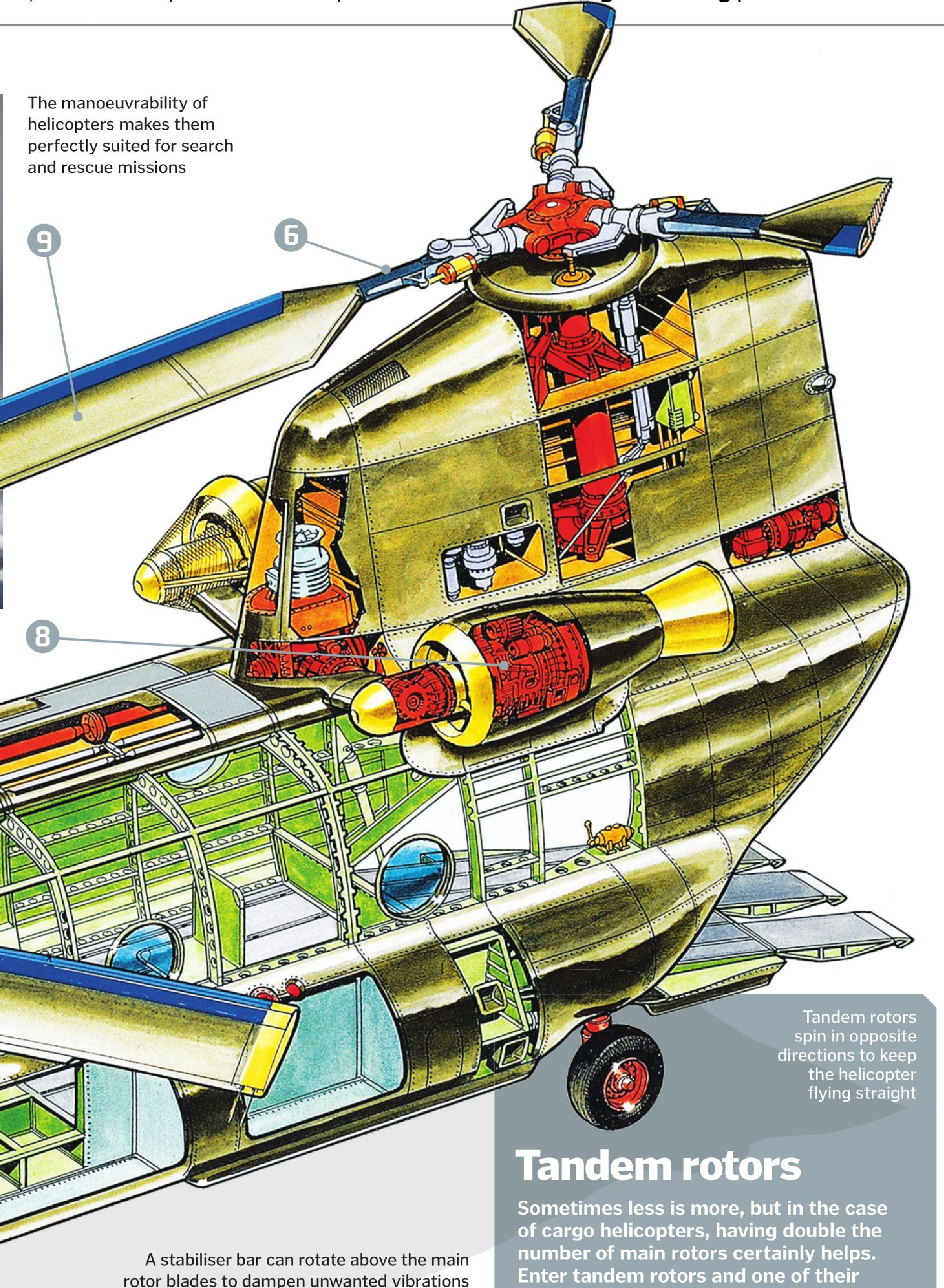
4 Upper swash plate The upper plate shares the lower plate's tilt but can spin freely, allowing it to be attached to the control rods.

5 Lower swash plate Steering controls from the cockpit are relayed to this lower plate, which tilts to influence the upper plate.

6 Changing pitch Increasing a blade's pitch (how vertical it is) will increase its lift. Increased lift at one location (e.g. the front) will change the helicopter's direction.

DID YOU KNOW? *The first manned flight of an electric-powered helicopter was achieved in August 2011 by pilot Pascal Chrétien*

The manoeuvrability of helicopters makes them perfectly suited for search and rescue missions



A stabiliser bar can rotate above the main rotor blades to dampen unwanted vibrations

7 Gearbox Both the main rotor and tail rotor are connected to a gearbox via a driveshaft.

8 Engine Helicopters can use piston engines like those used in cars but more commonly now use gas turbines akin to jet engines.

9 Tail rotor As the main rotor rapidly spins the helicopter body will want to spin in the opposite direction. Tail rotors provide torque that negates this force, keeping the body straight.

10 Cockpit Helicopter pilots must simultaneously control pitch and the throttle to keep the vehicle moving in the right direction.

Tandem rotors spin in opposite directions to keep the helicopter flying straight

Tandem rotors

Sometimes less is more, but in the case of cargo helicopters, having double the number of main rotors certainly helps. Enter tandem rotors and one of their famous users, the Chinook. Developed by US Vertol in the late 1950s, the Chinook is used by Britain's RAF today for carrying heavy cargo either in its fuselage or tethered to its underside. Outside of warfare the Chinook has recently been used to re-supply snowbound farmers and to transport aggregate for defence against winter storms.

As well as providing additional lift, the helicopter's second rotor performs an important role that's usually covered by the tail rotor in smaller helicopters. The rotation of the main rotor creates an opposite rotational force on the helicopter's body. Tandem rotor machines use rotors that spin in opposite directions, cancelling out the counter-acting forces. The risk of collision between the opposite blades is also intelligently mitigated by connecting the rotors to the same transmission.

© Getty; Wiki; Illustration by Adrian mann

How go-karts work

These scaled-down racers are the ideal start for anyone who wants to get into competitive racing

Fast vehicles, race tracks and intense competition – kart racing is for real thrill-seekers. With competitive karts reaching speeds in excess of 160 kilometres per hour, karting is a recognised motor sport that is often the gateway into other forms of professional racing. Many motor racing icons, including Formula One's Lewis Hamilton and the Indy 500's Danica Patrick, began their careers in karting.

The sport started in 1956, when Art Ingels and Lou Borelli built the first kart with a modified lawnmower engine. In 1957, the GoKart Manufacturing Company was established as karting became increasingly popular in the US. The craze soon spread to other countries, inspiring people to build their own homemade karts. Before long, the first official races were held, and clubs like the Grand Prix Kart Club of America and the International Karting Commission were established to monitor and promote the sport.

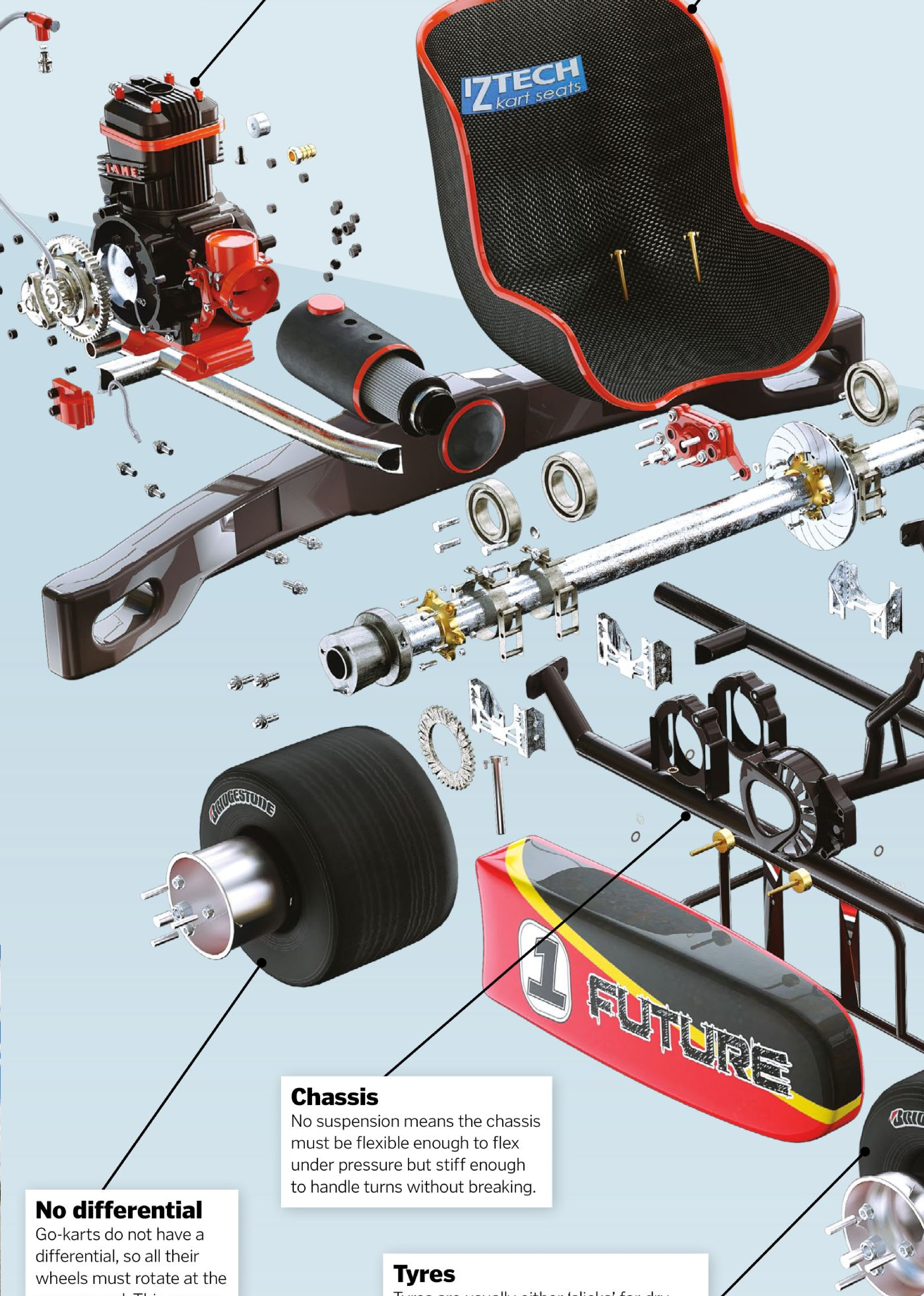
Today, the International Karting Commission is the largest regulating body of karting in the world, headed by former Formula One driver Felipe Massa. In the US, the sport is overseen by the World Karting Association, which has had over 50,000 members since it was founded in 1971.

The main type of kart used in competitive racing is a sprint because they are both fast and versatile enough to be used on a variety of different tracks. The other two types are endurance, which are the smallest and fastest of racing karts (usually averaging speeds of over 140 kilometres per hour during a race), and oval, which are built specifically to turn tight corners in one direction in order to tackle oval tracks, like those used in NASCAR racing.

Professional karts are sleeker, faster and better designed than backyard go-karts

The mechanics of a go-kart

The components of these small racers are key to their speed and manoeuvrability



Engine
A small water-cooled two- or four-stroke engine powers the go-kart. Today, they are made specifically, but early go-karts used engines from lawnmowers and motorbikes.

Seat
A low seat for the driver keeps the centre of gravity close to the road to reduce the risk of the vehicle toppling over when taking corners.

Chassis
No suspension means the chassis must be flexible enough to flex under pressure but stiff enough to handle turns without breaking.

No differential
Go-karts do not have a differential, so all their wheels must rotate at the same speed. This means that one of the rear tyres must slide when the driver takes a corner.

Tyres
Tyres are usually either 'slicks' for dry tracks, or the grooved 'wets' for when it is raining. Spiked tyres are also available for go-karts racing in icy conditions.

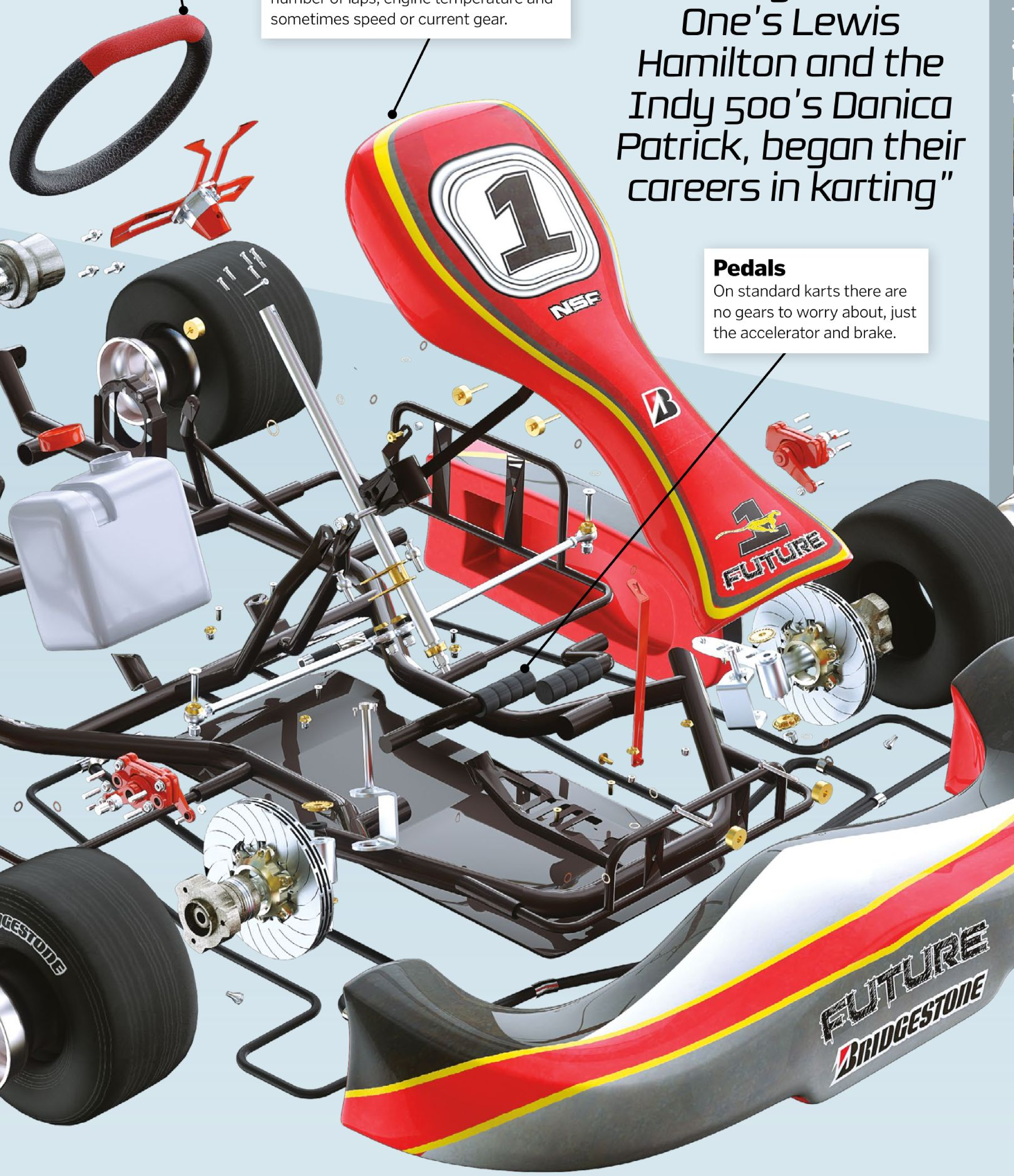
Not just a motor sport, go-karting is also a popular recreational activity

Steering wheel
The steering controls the back wheels, as karts are rear-wheel drive.

Data acquisition system
The driver can monitor information about their kart and the race, including engine revolutions per minute, lap times, number of laps, engine temperature and sometimes speed or current gear.

> *"Many motor racing icons, including Formula One's Lewis Hamilton and the Indy 500's Danica Patrick, began their careers in karting"*

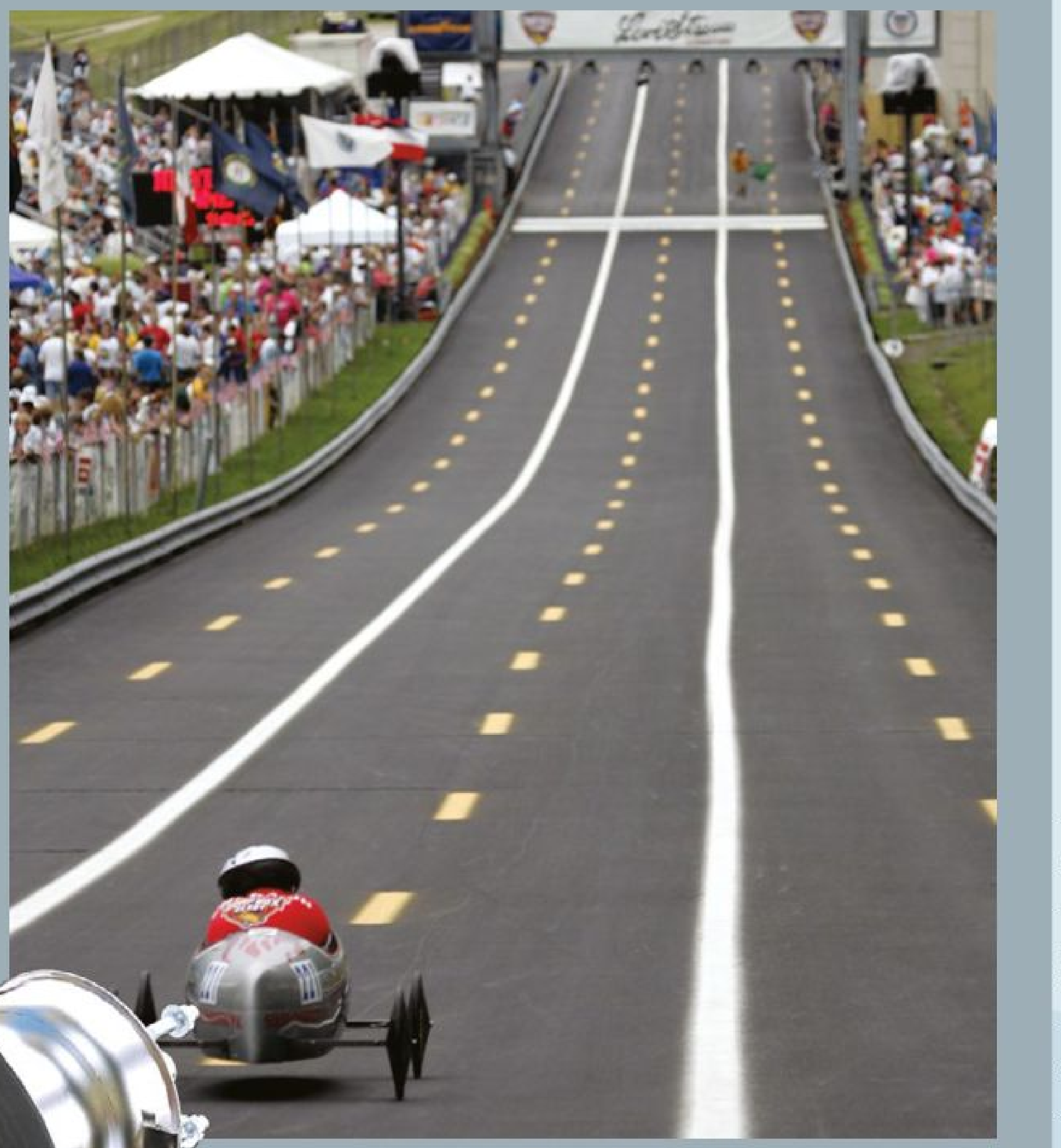
Pedals
On standard karts there are no gears to worry about, just the accelerator and brake.



Dimensions
Karts are usually around 1.8m long, 1.3m wide and weigh about 68kg.

Soap Box Derby racers

These gravity-powered home-built karts are part of a racing programme that started in the US in 1934. With no engine, they rely entirely on gravity to race down a steep road. Traditionally, they are made by children and young adults. The karts might look quite simple, but they can reach speeds exceeding 48 kilometres per hour, and people from around the world compete at the annual Soap Box Derby World Championship finals at the Derby Downs Track in Akron, Ohio. The racers start at a ramp at the top of a hill and before quickly accelerating downhill. The race is over in less than 30 seconds, and a timing-triggered overhead photography system is used to determine the winner of each heat.



The Soap Box racers are often brightly decorated

© Getty; Illustration by Nicholas Forder

Drivers can start entering karting competitions once they are eight years old

Abrams M1 Battletank

74-ton, 1,500-horsepower behemoth fires long-range cannons

Imagine driving one of these on your morning commute. The M1 Abrams tank, used throughout the Eighties and Nineties for both Gulf wars, and still more advanced than any other tank on the planet, is a 74-ton monster that can crash through walls and over terrain.

"The design of this tank is what makes it unique from its first inception," says Mike Peck, the director of business development at General Dynamics, who designs and manufactures the M1. According to Peck, the M1 uses a "combat platform" suspension with a low-to-the-ground chassis with a contoured body that allows the turret to be nestled down lower than other tanks, making the tank about three feet lower to the ground than similar vehicles. In the mid-Nineties, the M1 was updated with all digital components. Peck says it actually has more electronics than an F16 fighter.

Kevin Benson, a retired Lt Colonel who commanded entire battalions of M1 tanks, says the main advantage of the M1 is that it can fire 120mm rounds up to 3,000-4,000m whereas other tanks – especially those used by Iraqi forces in Operation Desert Storm – could only fire about 1,500m. In that campaign, US forces would surround the Iraqi tanks, safely out of range but well within the range of the M1. Peck says the M1 has a forward-range infrared sensor that works in day or night for long-range shots.

The engine on the M1 is also unique. It uses a turbine engine running at 1,500 horsepower, providing a distinct advantage: because the tank has such a high torque in the engine, it is almost unstoppable on the battlefield. "The engine has the most dense horsepower-per-weight ratio we could find," says Peck.

The M1 also has a pulse jet air cleaner to remove sand and other hazards, which Peck says has doubled the life of the engine. The tank is also outfitted with a 50 calibre machine gun that can turn 360-degrees, an aid for urban warfare. The M1 Abrams cruises at a top speed of 45 miles per hour on paved roads or 35 miles per hour over sand.

The approaching camel didn't know what hit it…

Abrams M1 in action

Just what makes the Abrams M1 so formidable?

Long-range, 120mm rounds

Benson says a key feature on the M1 is that it fires 120mm rounds up to 4,000m, a decided advantage on the battlefield. The rounds are made of high-density steel, travel one mile per second, and weigh around 30 pounds. "It's like firing a big nail," says Benson.

Heavy armour protection

Both Peck and Benson said another key advantage is that the tank is heavily armoured. Peck says he has never seen a tank that came back for repairs with any noticeable dents; many have fought in multiple campaigns and are still in prime condition.

High-torque engine

According to Benson, the high-torque engine on the M1 is extremely advanced: it uses a form of jet fuel and produces so much energy that, even at 74 tons, the tank can reach speeds approaching 45 miles per hour.

A US tank provides suppressive counter fire in Fallujah, Iraq

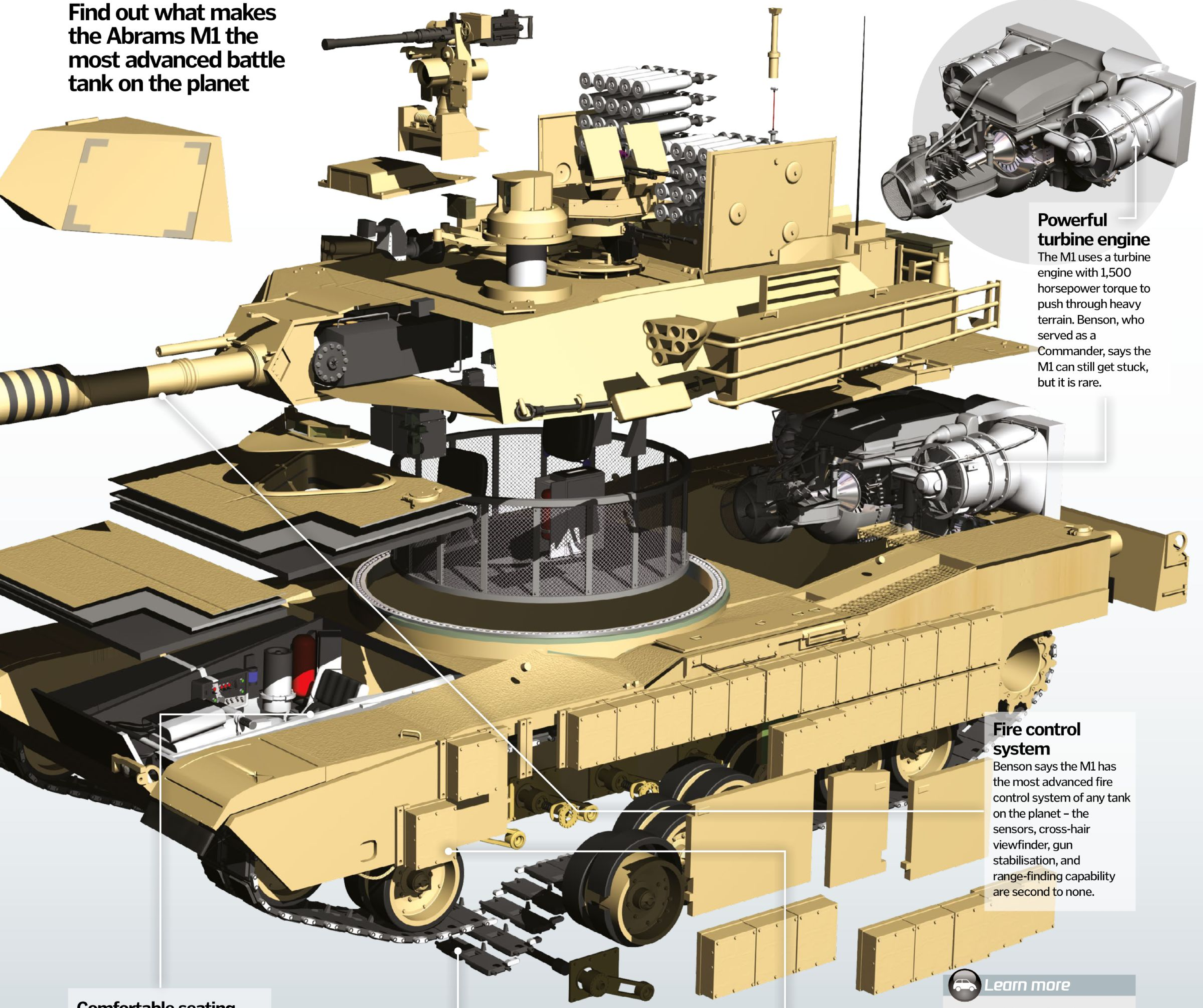
THE STATS
M1 TANK

GUN RANGE **4,000m**
ROUND LENGTH **120mm**
TRACK WEIGHT **2 tons**
WEIGHT **74 tons**
ROUND WEIGHT **30lbs**
FIRST ENTERED SERVICE **1980**

DID YOU KNOW? *TUSK (Tank Urban Survival Kit) allows commanders to fire using an LCD viewfinder*

Under the hood of the Abrams M1

Find out what makes the Abrams M1 the most advanced battle tank on the planet



Powerful turbine engine

The M1 uses a turbine engine with 1,500 horsepower torque to push through heavy terrain. Benson, who served as a Commander, says the M1 can still get stuck, but it is rare.

Fire control system

Benson says the M1 has the most advanced fire control system of any tank on the planet – the sensors, cross-hair viewfinder, gun stabilisation, and range-finding capability are second to none.

Comfortable seating

The M1 drives like a car – it has a steering wheel and foot pedals, says Benson (some models use levers for forward and back). Peck says he knows of a gunner who sat comfortably during a Baghdad campaign for 75 hours straight.

Two-ton tracks

The heavy tracks that propel the tank are made of a hard rubber with steel pins that hold it all together. Benson says the soldiers in the tank know how to quickly fix any track problems on the battlefield.

Chassis

The chassis of the M1 is what makes the tank able to withstand abuse. Peck says M1 tanks can go through a re-build process three or four times, adding new digital components.

Learn more

For more information about the M1 Abrams tank visit **www.army-technology.com** where you can read more about this destructive behemoth, as well as other lethal weapons used in 21st Century combat.

Illustrations © Alex Pang

C-130 Hercules

One of the longest-lasting and most widespread military transport vehicles of all time, the C-130 Hercules remains to this day an aerial behemoth, capable of flying thousands of miles to deploy troops and vehicles alike

The C-130 Hercules is a military transport aircraft famed for its durability and versatility, having been in active service for over 50 years. Since its introduction in December 1957, over 40 models and variants of the Hercules have been produced and are used today by more than 60 nations worldwide.

The aircraft works by delivering a cavernous central fuselage in which the vast cargo bay can carry a plethora of civilians, soldiers, vehicles, equipment, weapons and supplies over huge distances. This makes the Hercules an ideal tool to aid military operations in the 21st-century battlefield, a global theatre of war where mission parameters often need to adapt fluidly and at high speed.

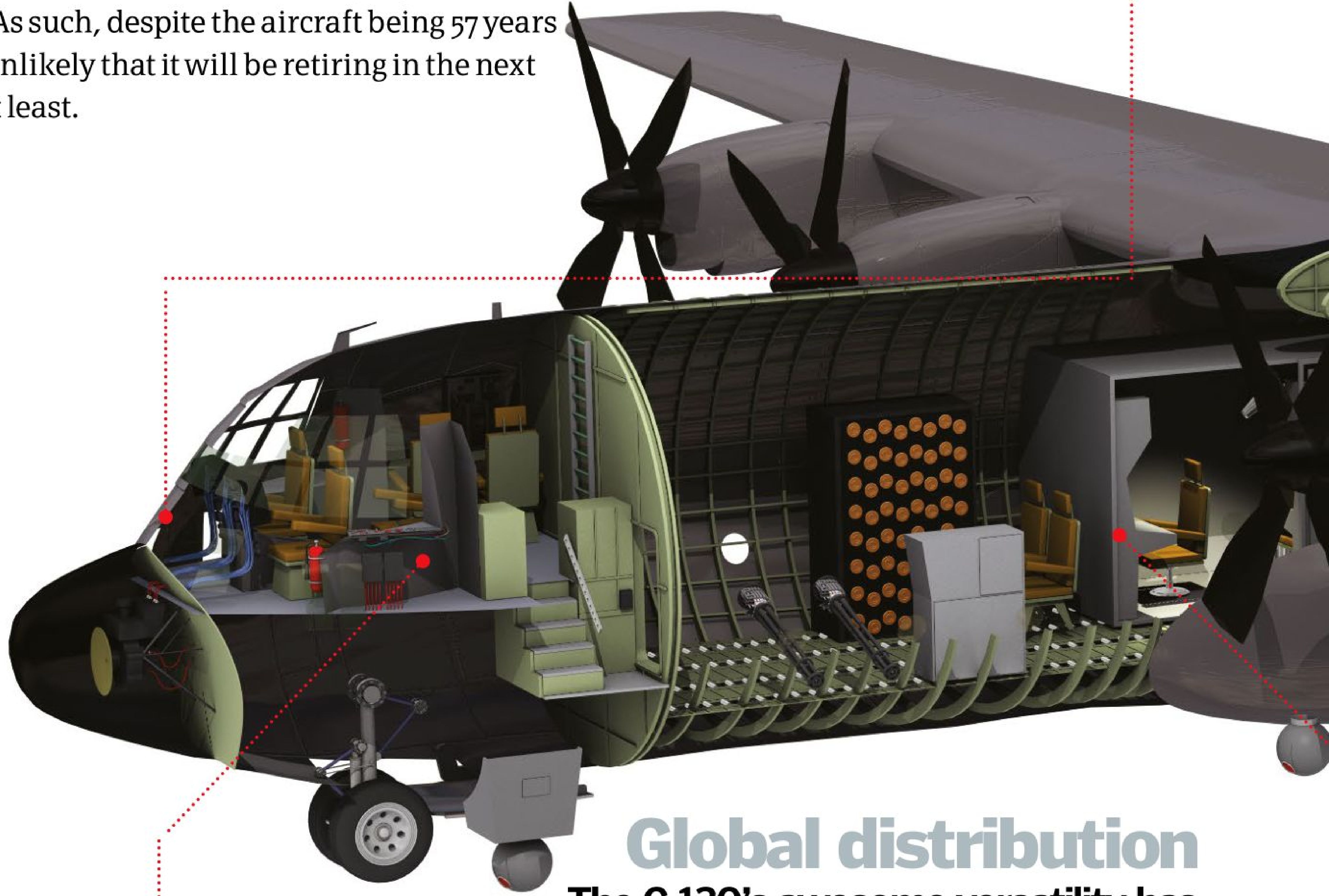
Indeed, the sheer lifting power of the C-130 cannot be overstated, with a single plane capable of lifting northwards of 33,000 kilograms (72,753 pounds). To put that in context, that is an ability to lift the equivalent of seven fully grown African elephants or 44 Mini Metros! As a heavy-lifting workhorse, the C-130 has few competitors capable of matching it and, as such, has seen off several contenders that were supposed to replace it (such as the C-5 Galaxy) and even spawned a larger but rarer Super Hercules variant.

All that lift comes courtesy of four Allison T56 turboprop jet engines, each capable of generating 3,423 kilowatts (4,590 shaft horsepower). The combined output makes this plane more powerful than 15 Bugatti Veyron Super Sports – the most powerful car on the planet. It also means the Hercules can not just lift more than 33,000 kilograms (72,753 pounds), but it can do so at both high altitude (the C-130 has a service ceiling of 10,000 metres (33,000 feet) and at high speed, with a cruise speed of 541 kilometres (336 miles) per hour. In addition, the titanic turboprops allow the Hercules to climb at a rate of 9.3 metres (31 feet) per second, a fact that allows it to quickly get airborne and out of range of many anti-aircraft armaments.

Interestingly, despite the US Air Force aiming to instigate a programme to produce a replacement for the C-130 in 2014 – for eventual delivery in 2024 – uptake for the programme has not been marked. Further, in December 2011, Lockheed Martin – the manufacturer of the Hercules – announced two new variants of the Hercules: the C-130XJ and C-130NG. As such, despite the aircraft being 57 years old, it is unlikely that it will be retiring in the next decade at least.

Avionics

Later models in the H series of C-130s are installed with ring laser gyros, GPS receivers, an upgraded APN-241 colour weather and navigational radar, improved generator control and bus switching units as well as an integrated radar and missile warning system.

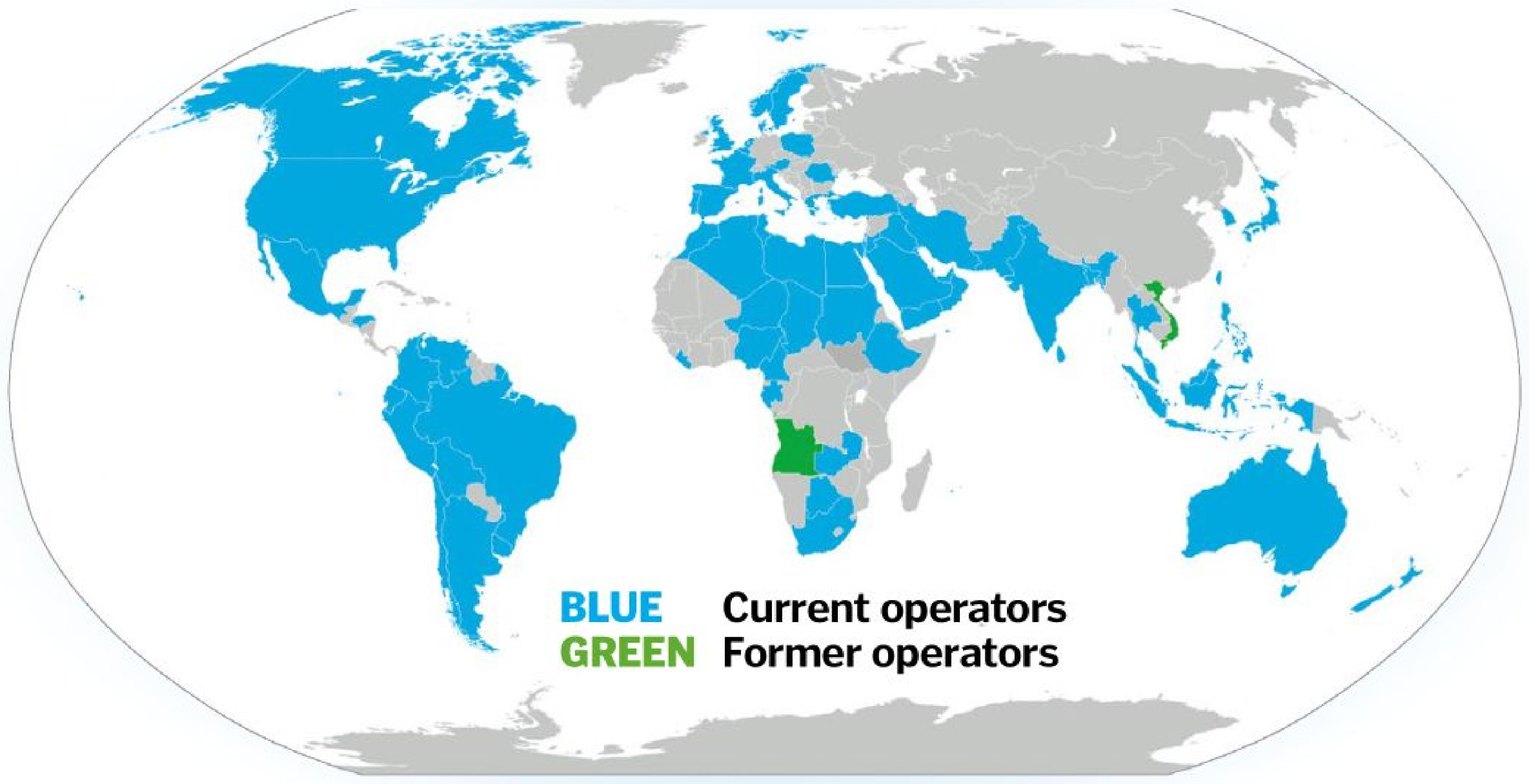


Crew

Due to its tremendous size and flexible capabilities, the C-130H is manned by five crew members. There are two pilots, a navigator, flight engineer and loadmaster. Due to its large carrying capacity, the loadmaster's role is to determine how to most efficiently load huge and diverse cargo.

Global distribution

The C-130's awesome versatility has seen it adopted the world over



BLUE Current operators
GREEN Former operators

5 TOP FACTS
HERCULES C-130

Versatile

1 *Despite being introduced in the Fifties, the Hercules C-130 is still a mainstay of militaries worldwide, with over 2,300 built and over 40 different variants in use today.*

Elite

2 *As of 2012, only five aircraft have been used continuously for over 50 years. The C-130, English Electric Canberra, Boeing B-52 Stratofortress, Tupolev Tu-95 and Boeing KC-135 Stratotanker.*

Georgia

3 *The original prototype was produced in California, where it took its first flight. Since production began, however, all C-130s have been built in Marietta, Georgia.*

Super

4 *A larger, more advanced version of the C-130 is currently being produced – the C-130J Super Hercules. As of November 2011, 250 have been built and deployed.*

Upgrade

5 *In 2010 the Pentagon approved funding for a selection of C-130s to be upgraded with an Avionics Modernization Program (AMP) kit. A total of 198 C-130s will feature the upgrade.*

DID YOU KNOW? The Hercules C-130 was first introduced in December 1957

The C-130 is one of a prestigious group of only six aircraft to have been in continuous service for over 50 years

The statistics...

Hercules C-130

Crew: 5

Length: 29.8m (97ft 9in)

Wingspan: 40.4m (132ft 7in)

Height: 11.6m (38ft 3in)

Capacity: 92 passengers; 64 airborne troops; 3 x Humvee; 2 x M113 troop carriers

Payload: 20,000kg (45,000lb)

Powerplant: 4 x Allison T56-A-15 turboprop (3,423kW/4,590shp each)

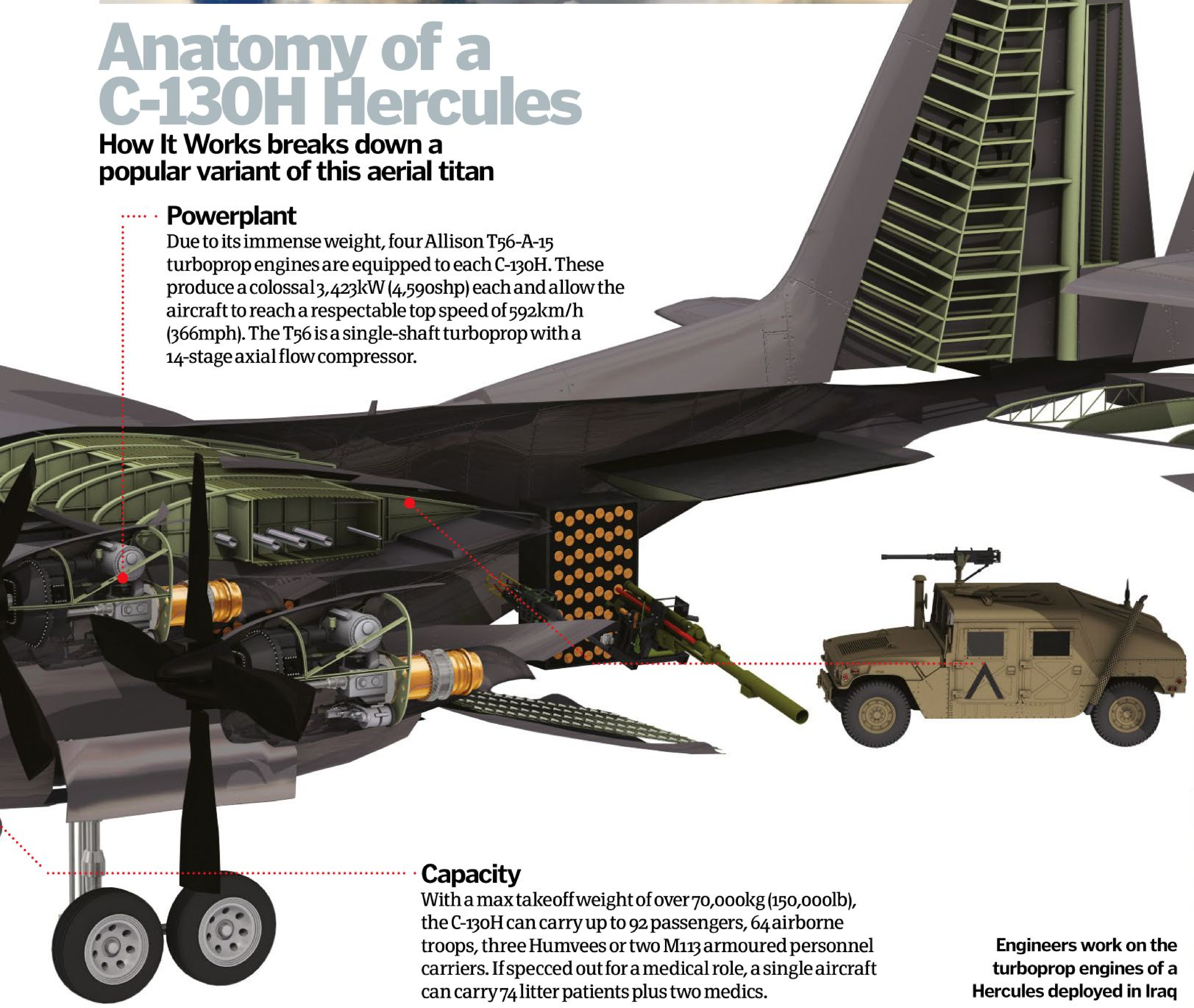
Max speed: 592km/h (366mph)

Max range: 3,800km (2,360mi)

Max altitude: 10,060m (33,000ft)

Anatomy of a C-130H Hercules

How It Works breaks down a popular variant of this aerial titan



Powerplant

Due to its immense weight, four Allison T56-A-15 turboprop engines are equipped to each C-130H. These produce a colossal 3,423kW (4,590shp) each and allow the aircraft to reach a respectable top speed of 592km/h (366mph). The T56 is a single-shaft turboprop with a 14-stage axial flow compressor.

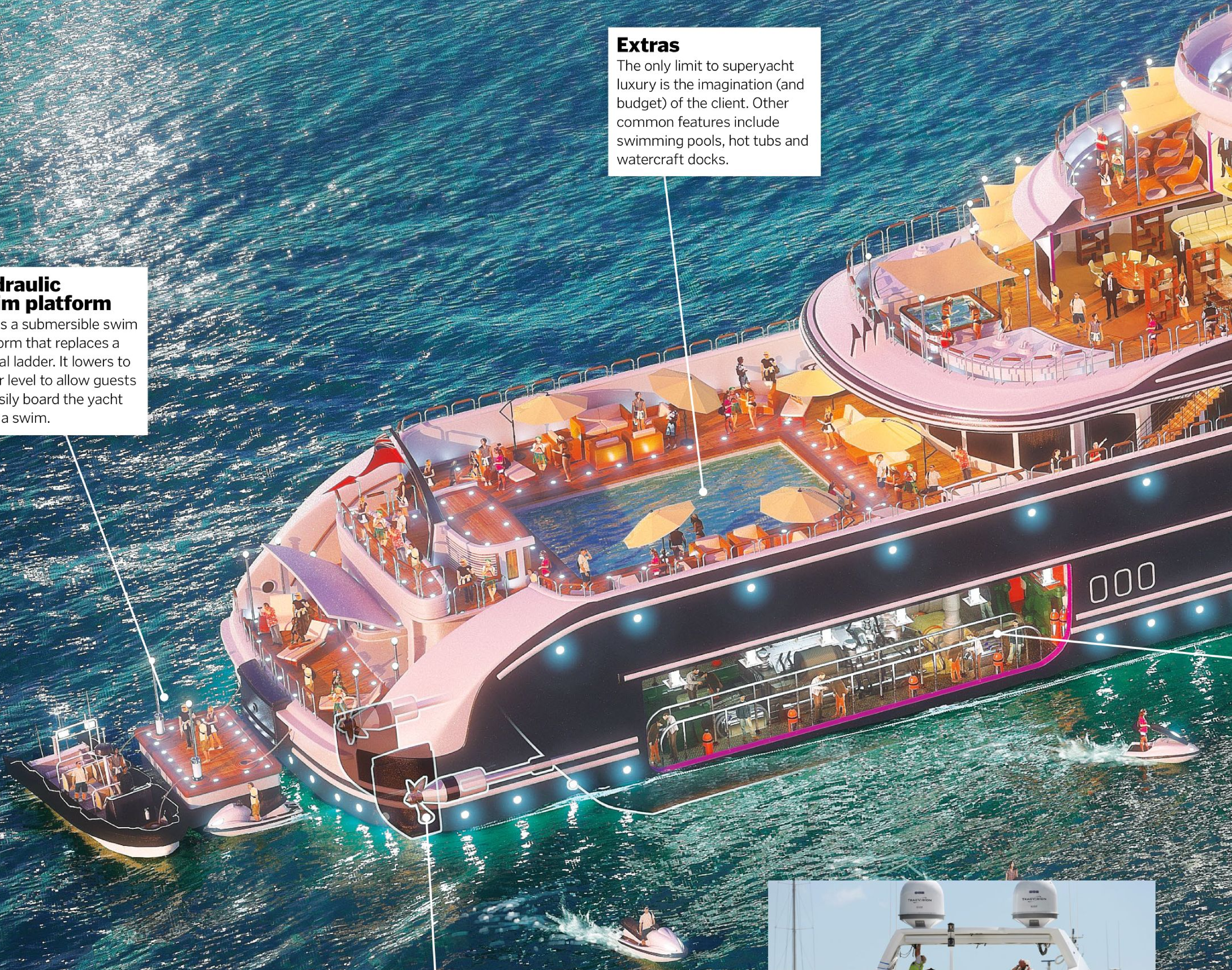
Capacity

With a max takeoff weight of over 70,000kg (150,000lb), the C-130H can carry up to 92 passengers, 64 airborne troops, three Humvees or two M113 armoured personnel carriers. If specced out for a medical role, a single aircraft can carry 74 litter patients plus two medics.

Engineers work on the turboprop engines of a Hercules deployed in Iraq

What makes a superyacht?

How these vessels combine luxury with the latest tech



Communication technology
GPS, radio and radar make navigating the open ocean easier and enable communication with onshore authorities and other ships.

Extras
The only limit to superyacht luxury is the imagination (and budget) of the client. Other common features include swimming pools, hot tubs and watercraft docks.

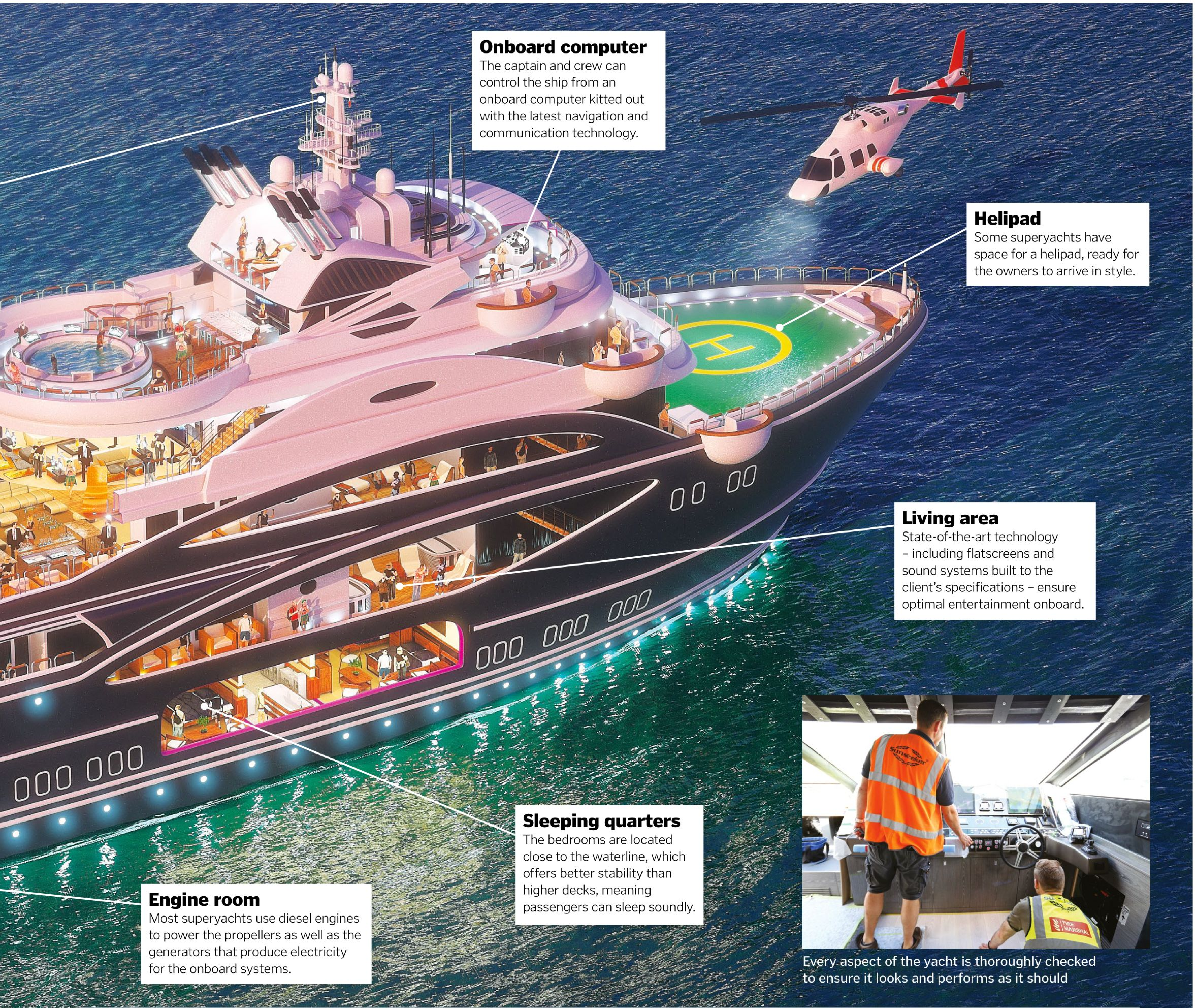
Hydraulic swim platform
This is a submersible swim platform that replaces a typical ladder. It lowers to water level to allow guests to easily board the yacht after a swim.

Propellers
Propellers are powered by the engines, providing the thrust required to drive and turn the yacht.

> "Virtual reality has become more popular, allowing designers to walk the client through their proposed design"

Once the yacht is finished it undergoes sea testing and final inspections before setting sail with its new owner

DID YOU KNOW? *One company claimed to have built a £3bn ($4.8bn) yacht with 100tn of gold and platinum… but it was a hoax!*



Onboard computer
The captain and crew can control the ship from an onboard computer kitted out with the latest navigation and communication technology.

Helipad
Some superyachts have space for a helipad, ready for the owners to arrive in style.

Living area
State-of-the-art technology – including flatscreens and sound systems built to the client's specifications – ensure optimal entertainment onboard.

Sleeping quarters
The bedrooms are located close to the waterline, which offers better stability than higher decks, meaning passengers can sleep soundly.

Engine room
Most superyachts use diesel engines to power the propellers as well as the generators that produce electricity for the onboard systems.

Every aspect of the yacht is thoroughly checked to ensure it looks and performs as it should

All aboard the mega yachts

Al Mirqab
This $250-million (£189.7-million) yacht was built for Qatar's former prime minister and foreign minister, Hamad bin Jassim bin Jaber Al Thani. It comes complete with onboard cinema, sun deck and swimming pool.

Dilbar
This giant superyacht is owned by Russian oligarch Alisher Usmanov, who uses the $256-million (£193.8-million) vessel – complete with its own distinctive helipad – to visit his private islands.

Eclipse
Russian billionaire Roman Abramovich owns this $1.5-billion (£1.1-billion) yacht, complete with a submarine and two helipads. It's also incredibly secure; it has a missile detection system and bulletproof windows.

Lady Moura
Saudi businessman Nasser Al-Rashid's $210-million (£159-million) Lady Moura has six decks and can carry a crew of 60 and 30 guests. It has a spa, a casino and even an operating theatre in case of emergencies.

Rising Sun
American entertainment magnate David Geffen owns this $200-million (£151.4-million), 138-metre-long superyacht. Its amenities include a movie theatre, helipad, basketball court and an extensive wine cellar.

© Getty; Illustration by Nicholas Forder

F-22 Raptor vs F-35 Lightning II

These American fighters are all but unmatched in the skies

At first glance, these two planes look quite similar, but beneath their exteriors lies very different technology. The F-22 Raptor, developed by Lockheed Martin and Boeing, has been in service since 2005, billed as the world's first stealth air-to-air fighter. Its curved body scatters incoming radio waves, ensuring the plane does not appear on scanners, and its weapons can be carried inside the fuselage, so it doesn't have any errant parts that might give its position away. It's capable of speeds of up to around Mach 2 and was the first US fighter able to 'supercruise', which means it can fly at supersonic speeds without using its afterburner, managing an impressive Mach 1.5 in this mode. This is thanks to two Pratt & Whitney F119-PW-100 engines.

Lockheed Martin's F-35 Lightning II Joint Strike Fighter (JSF), meanwhile, has a maximum speed of Mach 1.6. There are three variants: the F-35A, F-35B and F-35C, each with slightly different abilities. While it can't officially supercruise, it can maintain a speed of Mach 1.2 without its afterburners for a brief time, and like the F-22 it's designed to scatter radar waves and remain invisible on radar screens. It's outfitted with a single Pratt & Whitney F135 engine and, despite the delays, it's been described as one of the most advanced aircraft in the world. It's more suited to air-to-ground combat than the F-22, being able to carry more powerful bombs. Although it flew for the first time in 2006, it didn't enter service until 2015.

> "The F-35 is one of the most advanced aircraft in the world"

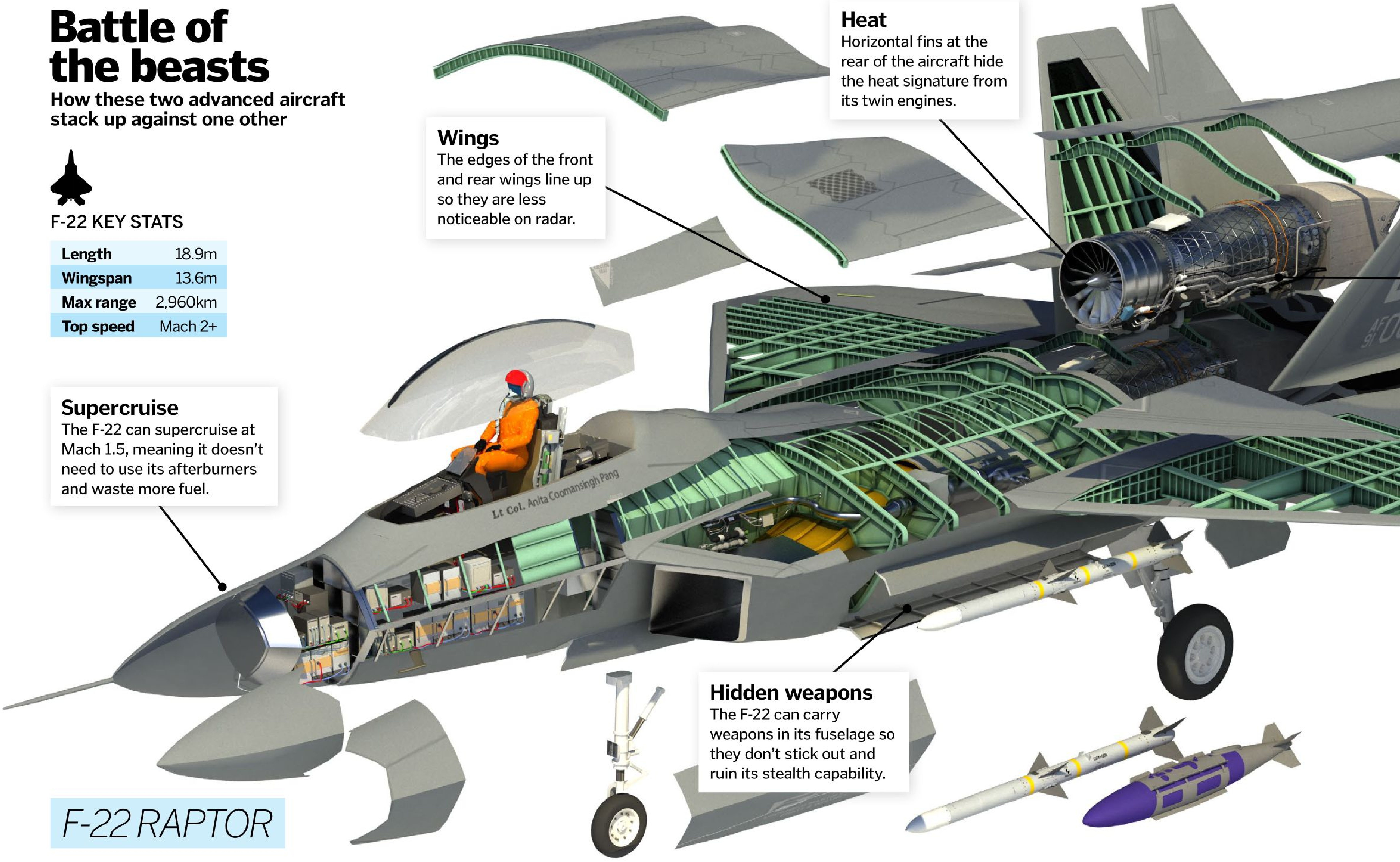
Fibre mat
The plane is built with absorbent materials, such as fibre mat, to give it a low radar profile.

Battle of the beasts

How these two advanced aircraft stack up against one other

F-22 KEY STATS

Length	18.9m
Wingspan	13.6m
Max range	2,960km
Top speed	Mach 2+



Supercruise
The F-22 can supercruise at Mach 1.5, meaning it doesn't need to use its afterburners and waste more fuel.

Wings
The edges of the front and rear wings line up so they are less noticeable on radar.

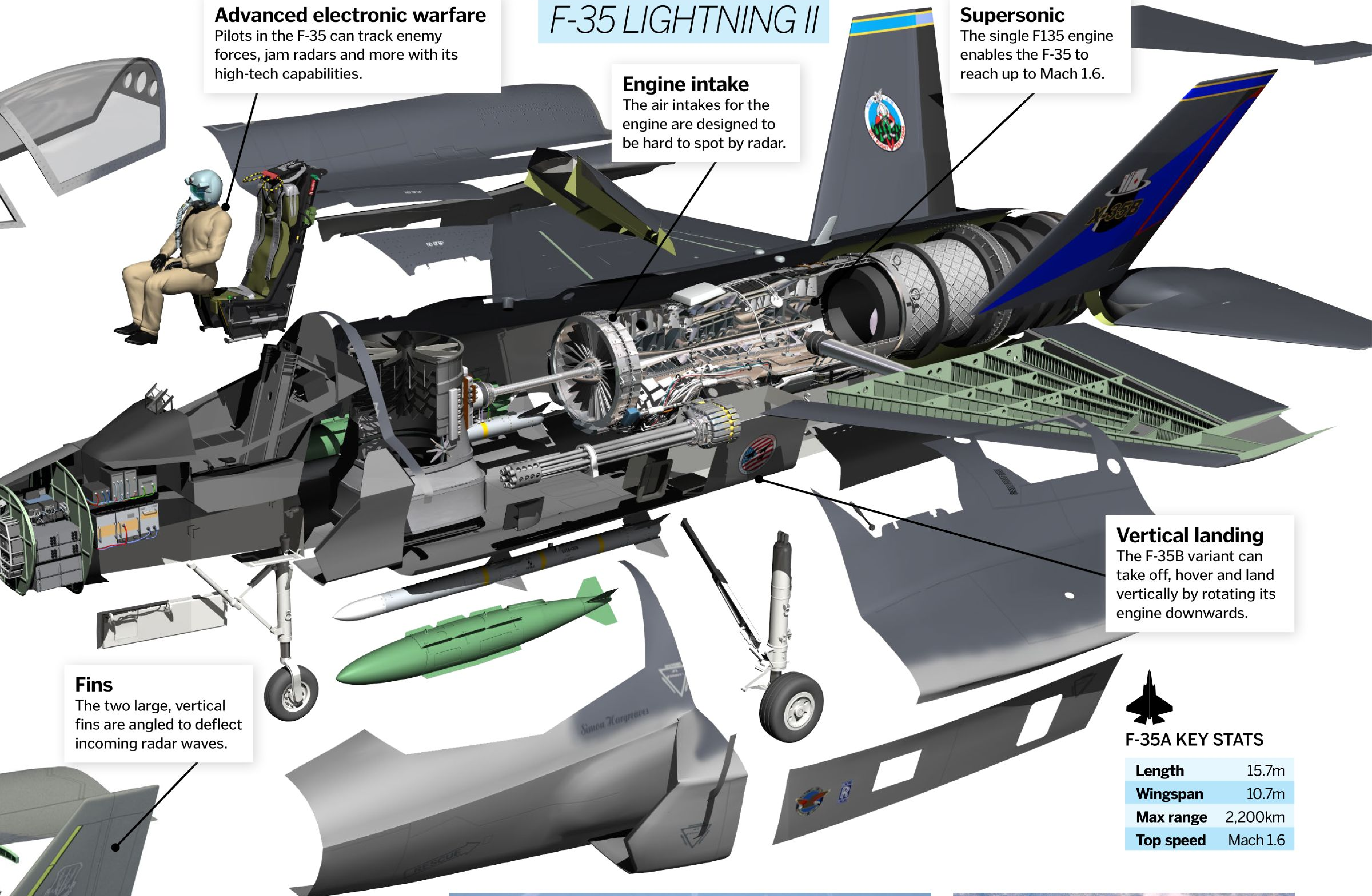
Heat
Horizontal fins at the rear of the aircraft hide the heat signature from its twin engines.

Hidden weapons
The F-22 can carry weapons in its fuselage so they don't stick out and ruin its stealth capability.

F-22 RAPTOR

DID YOU KNOW? The core processor onboard the F-35 aircraft is able to perform up to 400 billion operations per second!

F-35 LIGHTNING II

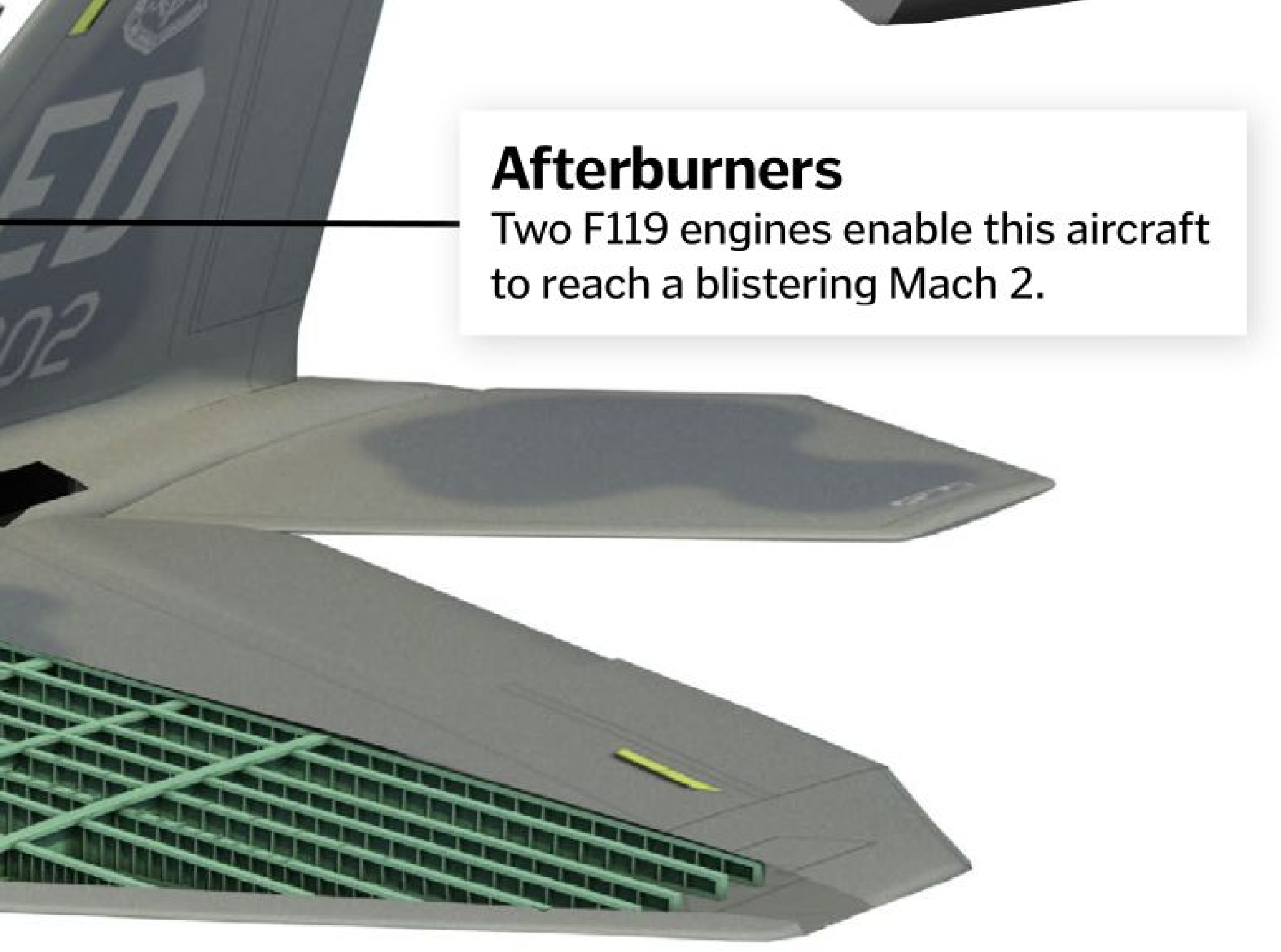


Advanced electronic warfare
Pilots in the F-35 can track enemy forces, jam radars and more with its high-tech capabilities.

Engine intake
The air intakes for the engine are designed to be hard to spot by radar.

Supersonic
The single F135 engine enables the F-35 to reach up to Mach 1.6.

Vertical landing
The F-35B variant can take off, hover and land vertically by rotating its engine downwards.



Fins
The two large, vertical fins are angled to deflect incoming radar waves.

Afterburners
Two F119 engines enable this aircraft to reach a blistering Mach 2.

F-35A KEY STATS

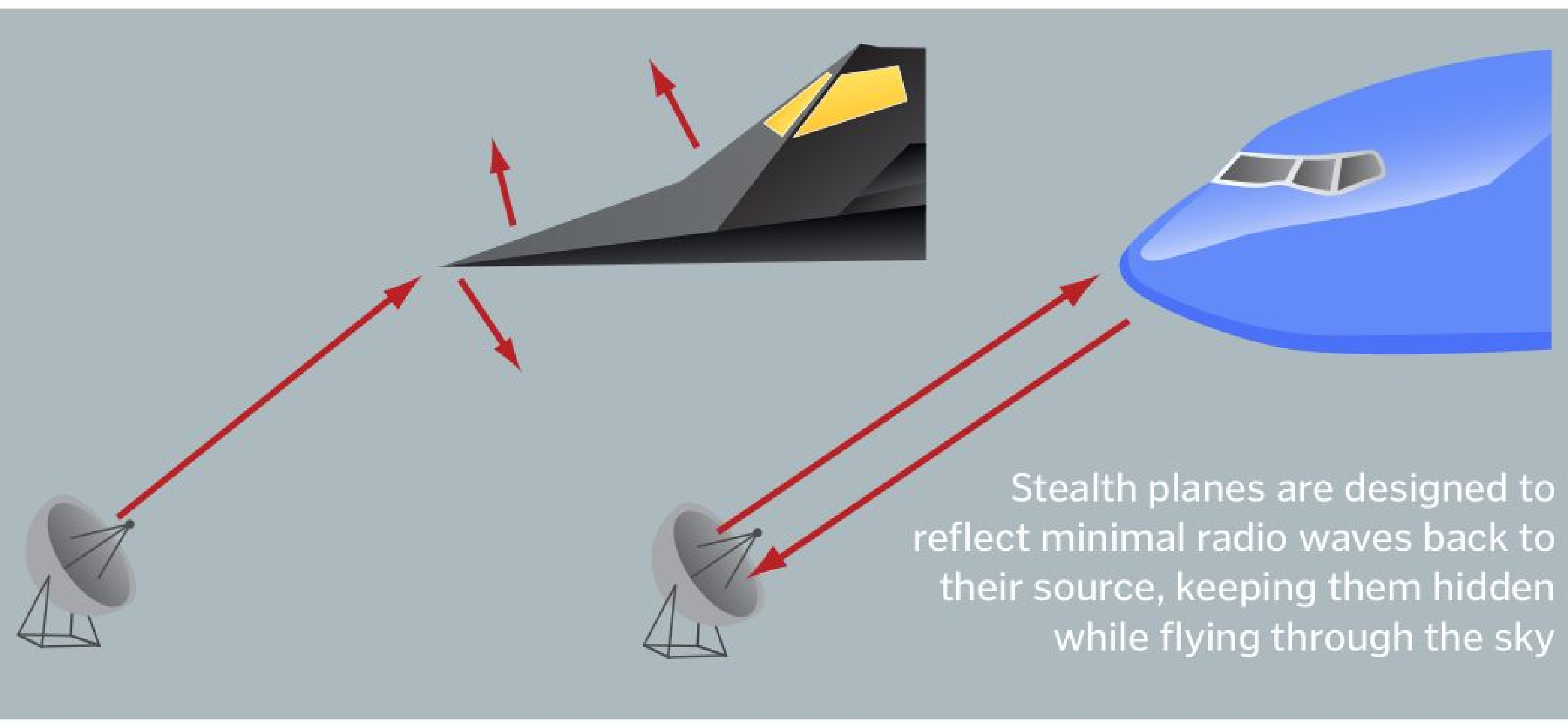
Length	15.7m
Wingspan	10.7m
Max range	2,200km
Top speed	Mach 1.6

The F-35 is the newest American fifth-generation fighter

The iconic B-2 bomber used stealth technology to deliver bombs undetected

Stealth technology

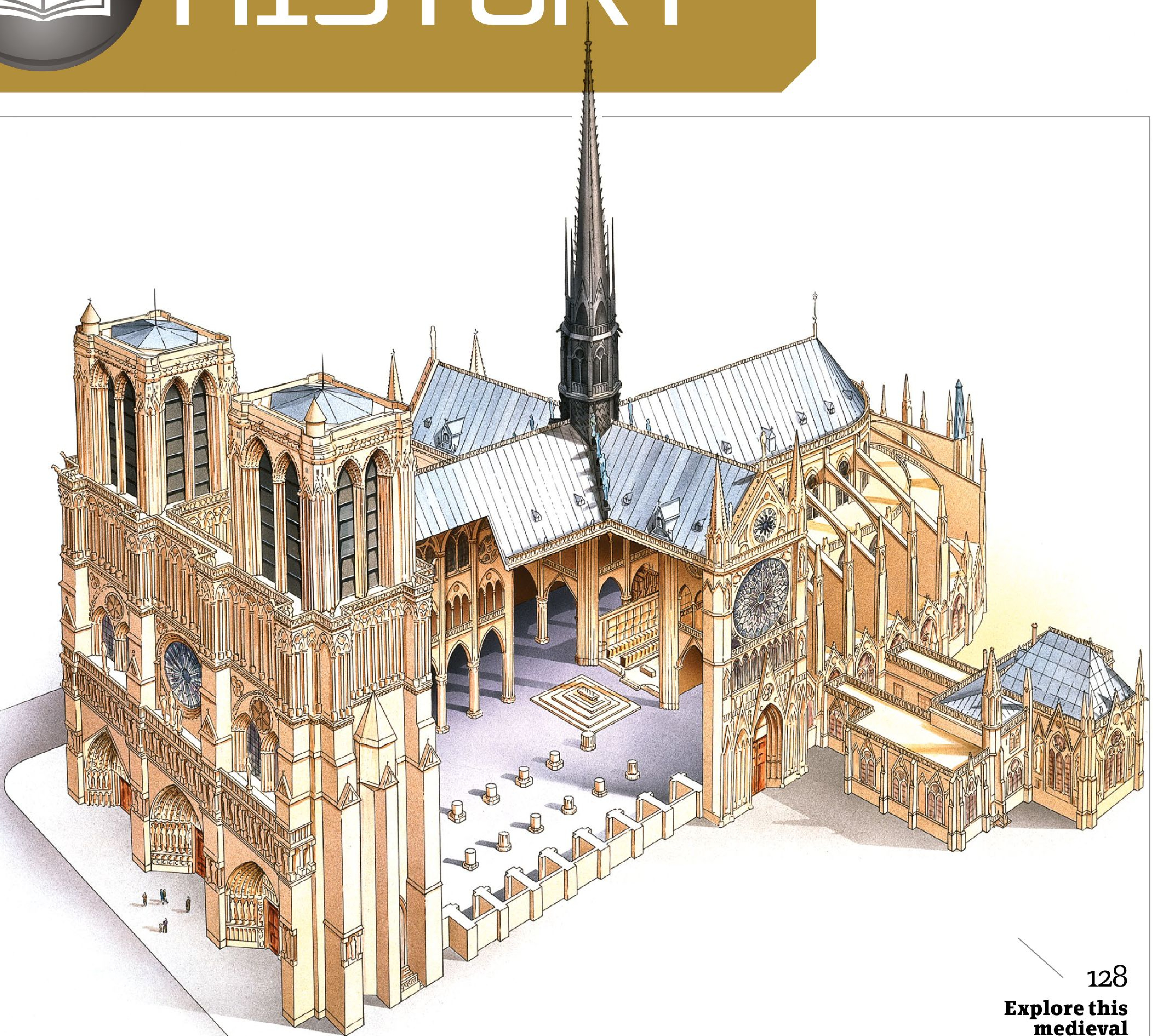
Radar systems are able to see planes by bouncing radio waves off them then measuring the time taken for the reflection to return to determine the position of the aircraft. But what if the waves never return? That's the basic idea around stealth planes, which are designed to reflect or scatter waves so that they go undetected. Some do this with their design, using conjoined edges and smooth surfaces to achieve a low RCS – the lower the better. Others use materials that absorb radar signals in order to produce a similar effect. While some stealth aircraft have a lower RCS than others, each fifth-generation fighter is able to keep itself hidden before it's time to strike.



Stealth planes are designed to reflect minimal radio waves back to their source, keeping them hidden while flying through the sky

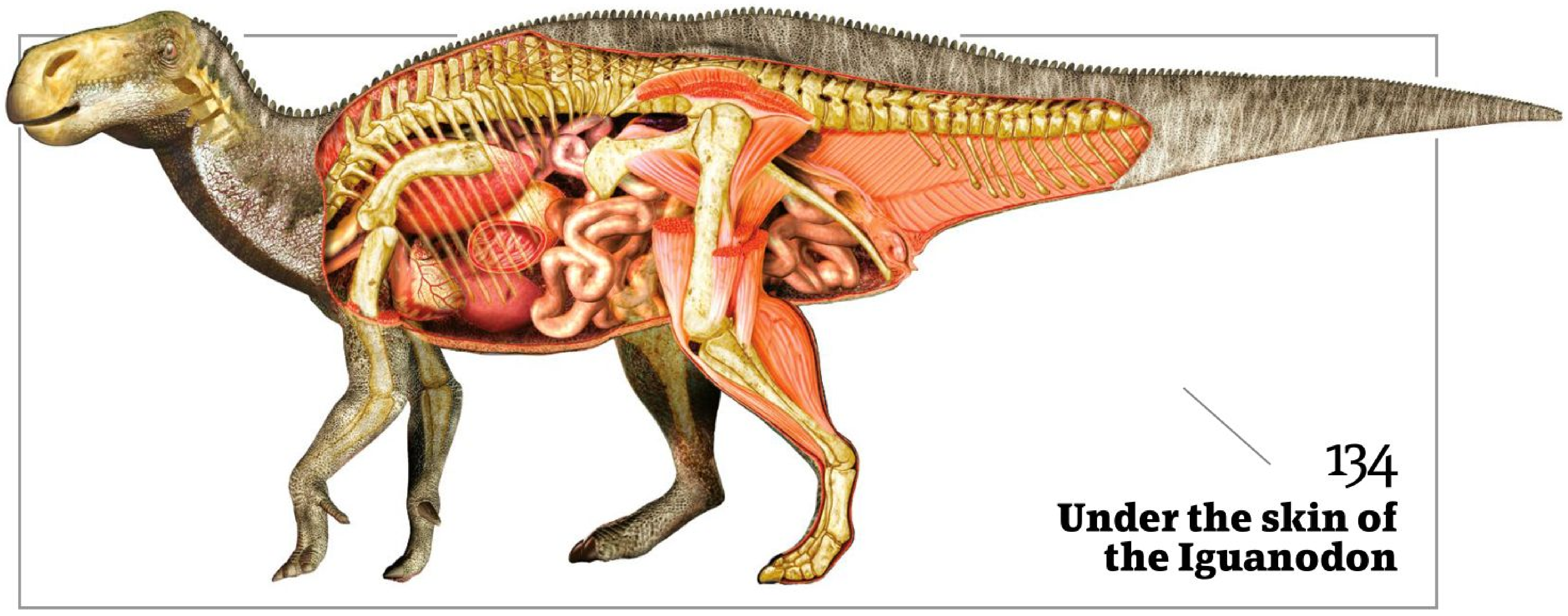
© Illustration: Alex Pang; Getty; 2018 Northrop Grumman Corporation

HISTORY

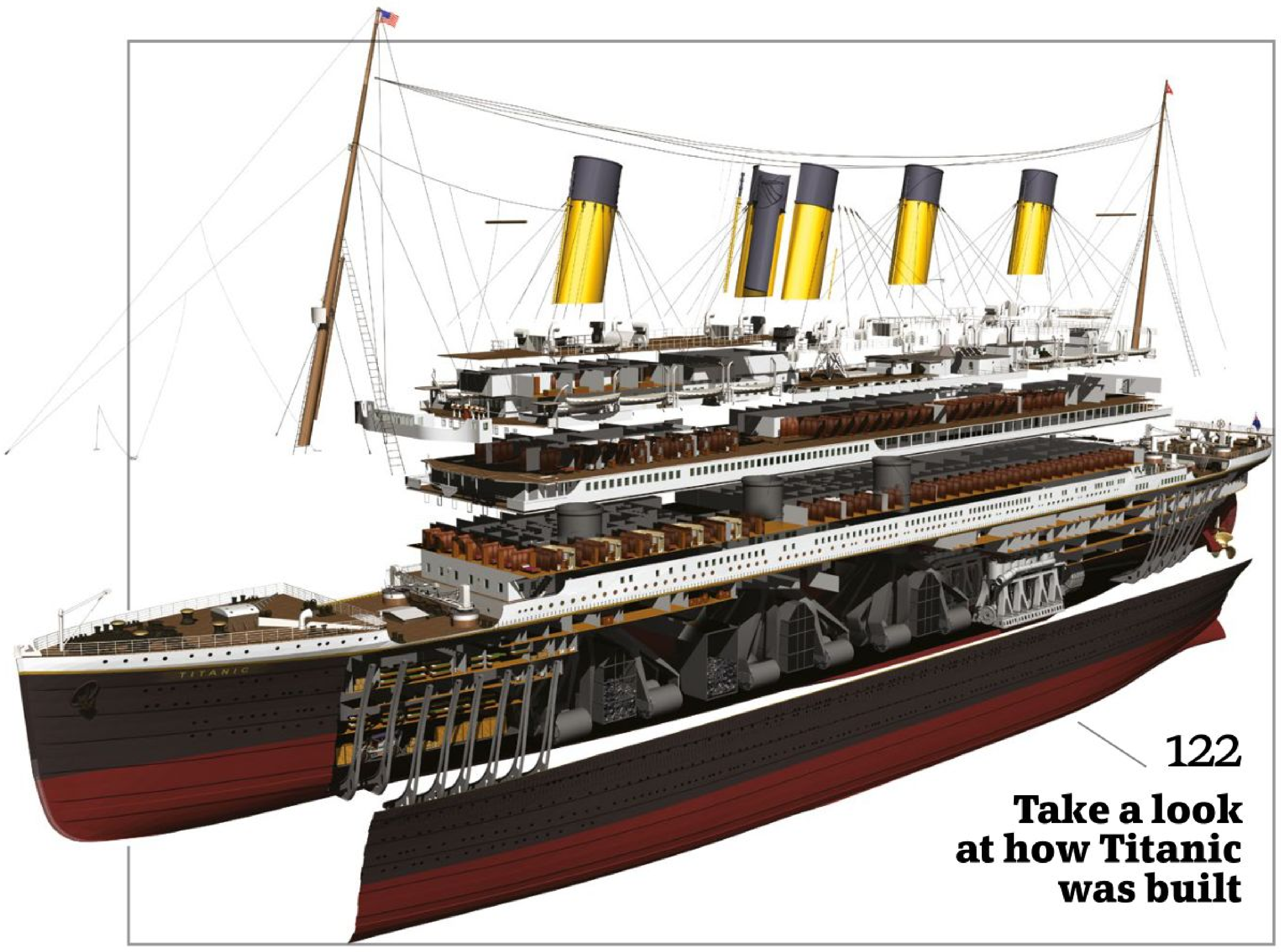


128
Explore this medieval marvel

122 The sinking of Titanic
126 Supermarine Spitfire
128 Rebuilding Notre-Dame
130 Fossils
132 Inside the White House
134 The Iguanodon
136 Hampton Court Palace
138 Tiger tank anatomy
140 Florence Cathedral
142 Picking the Pope

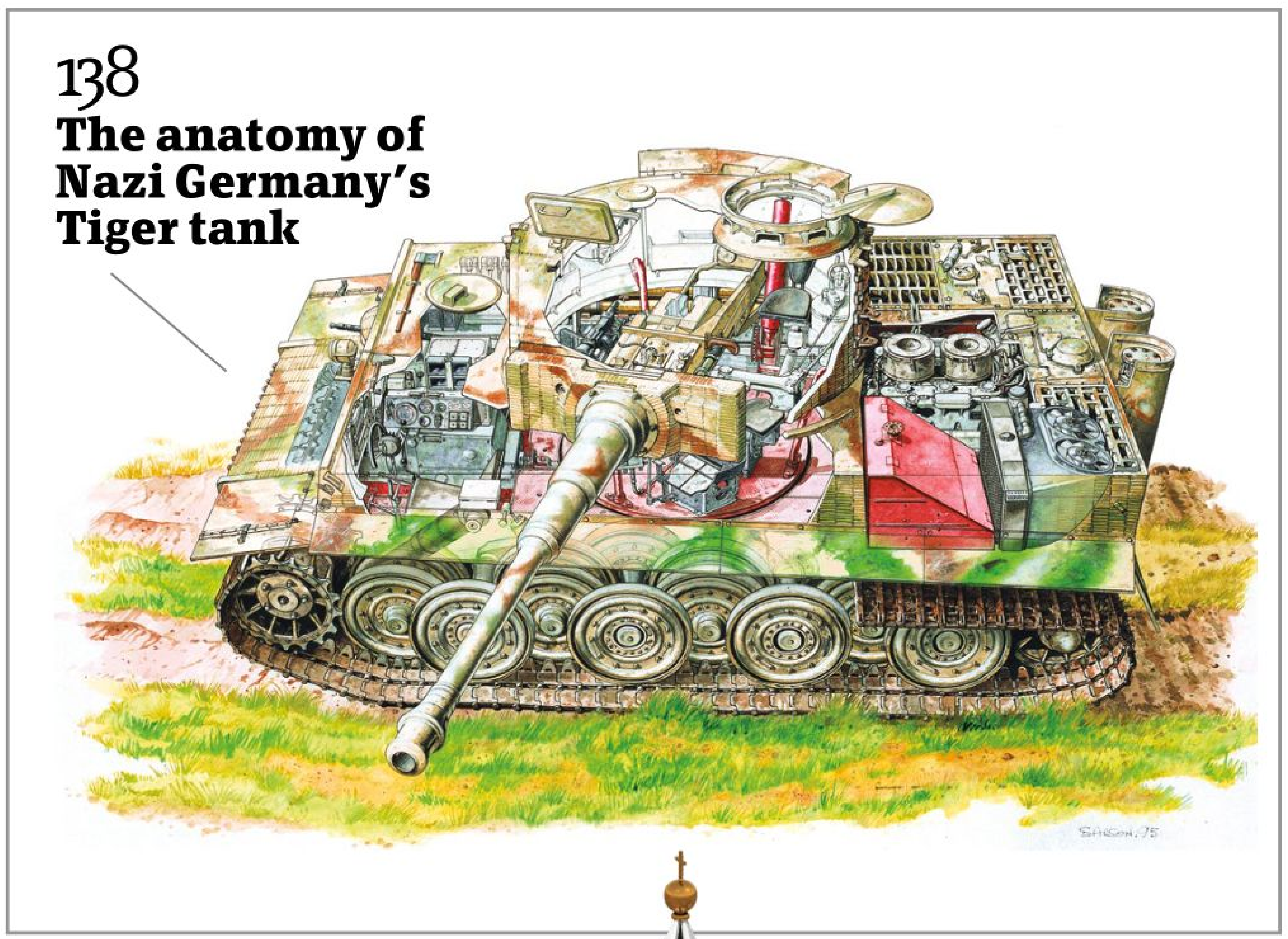


134
Under the skin of the Iguanodon



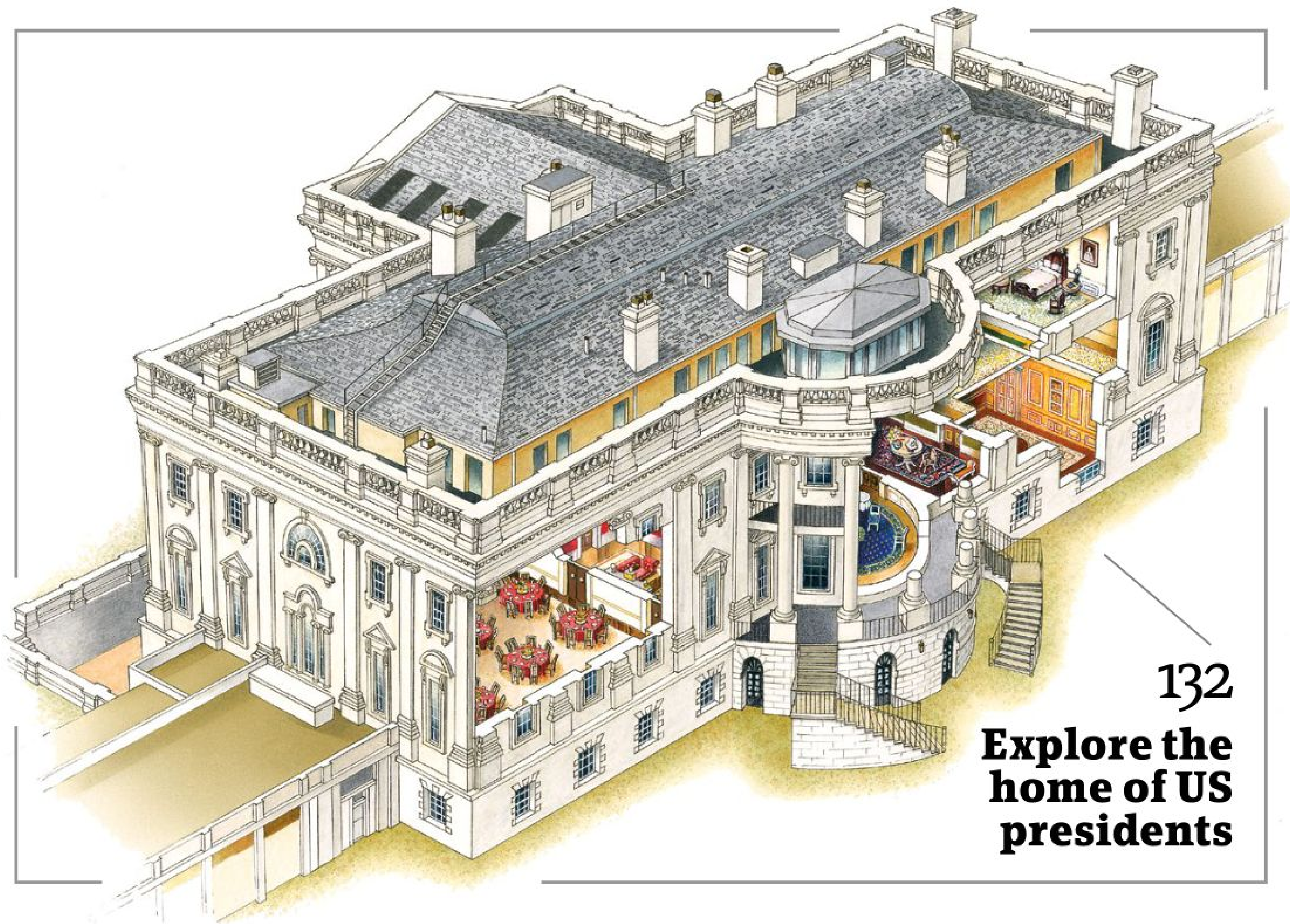
122

Take a look at how Titanic was built



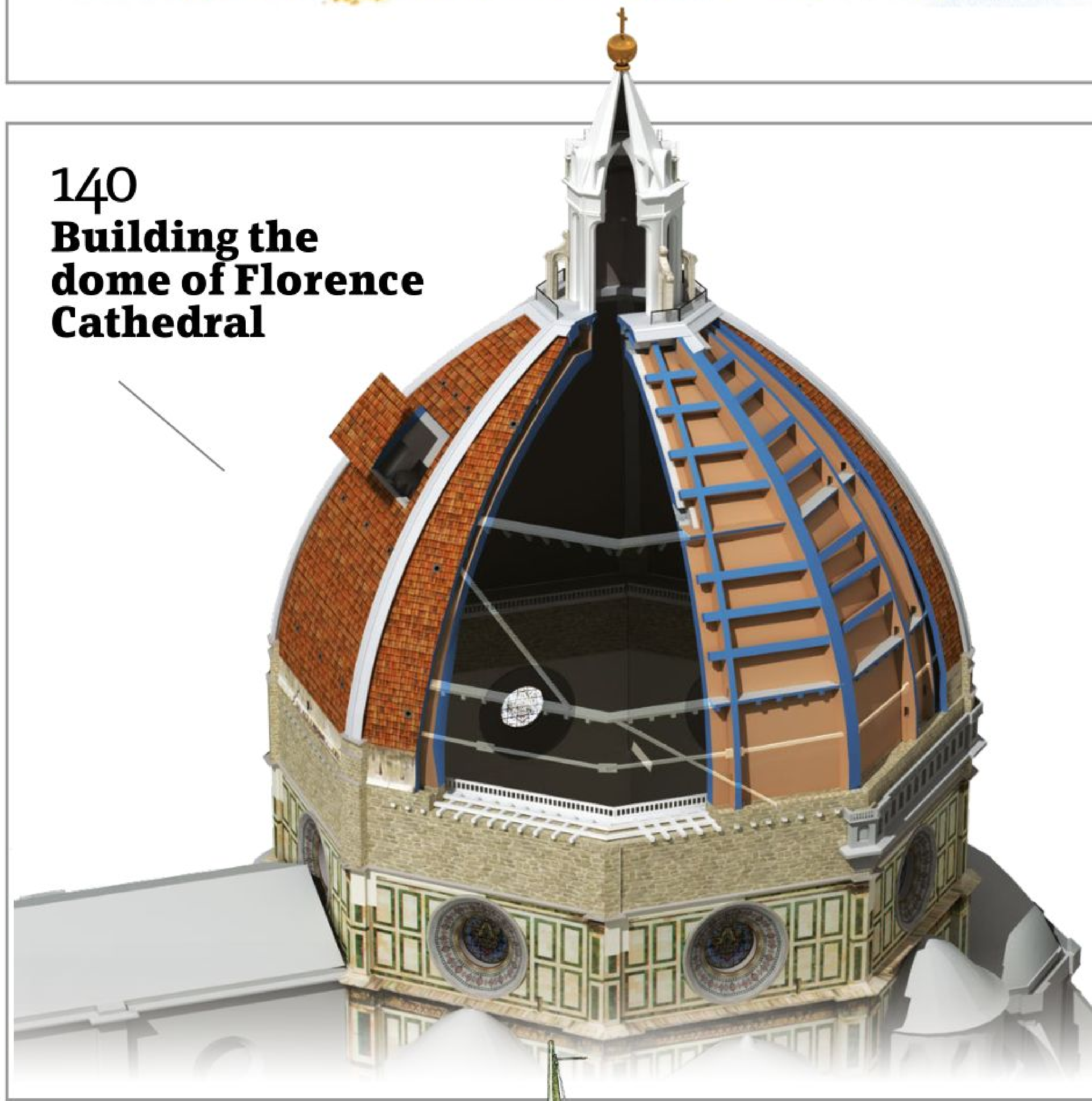
138

The anatomy of Nazi Germany's Tiger tank



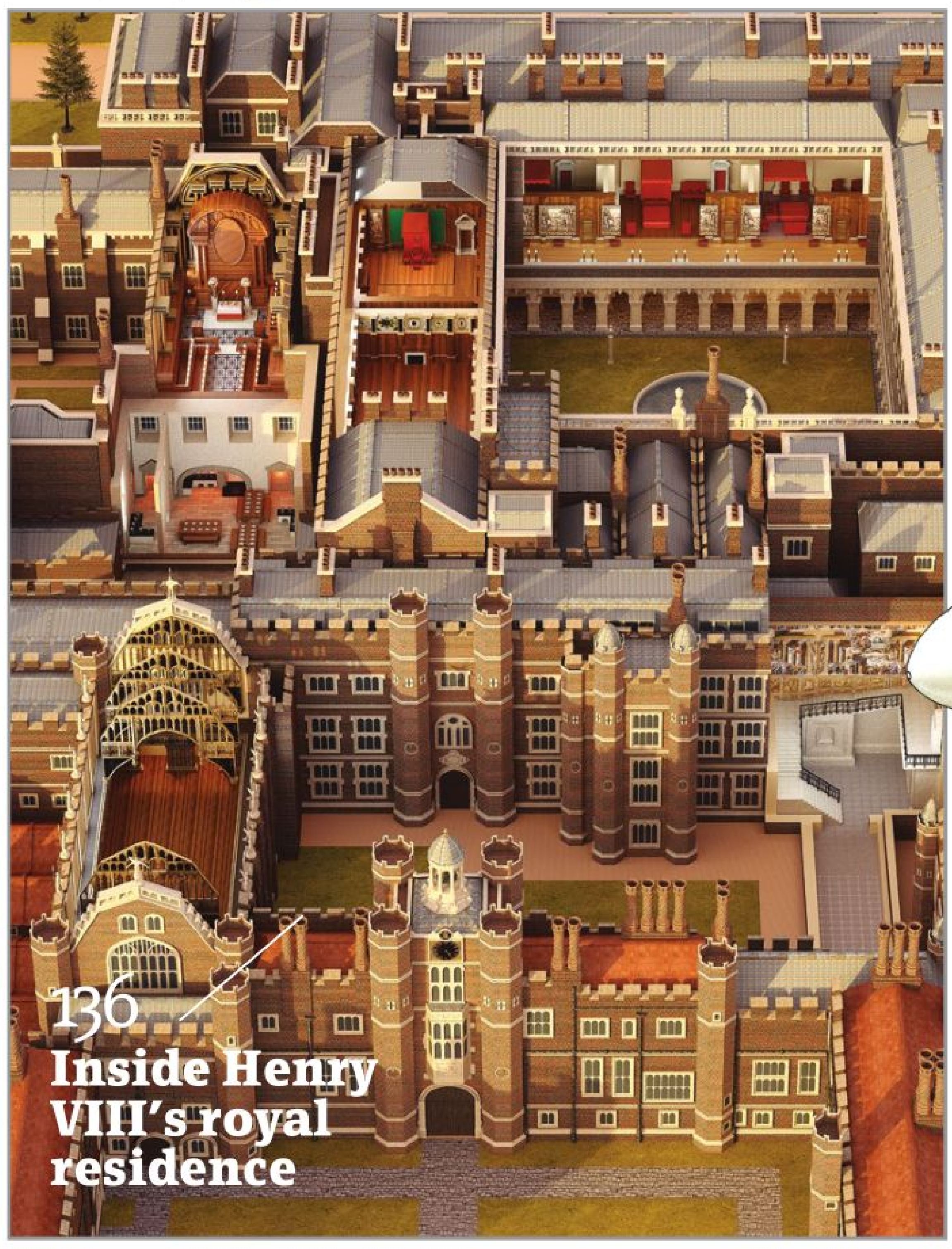
132

Explore the home of US presidents



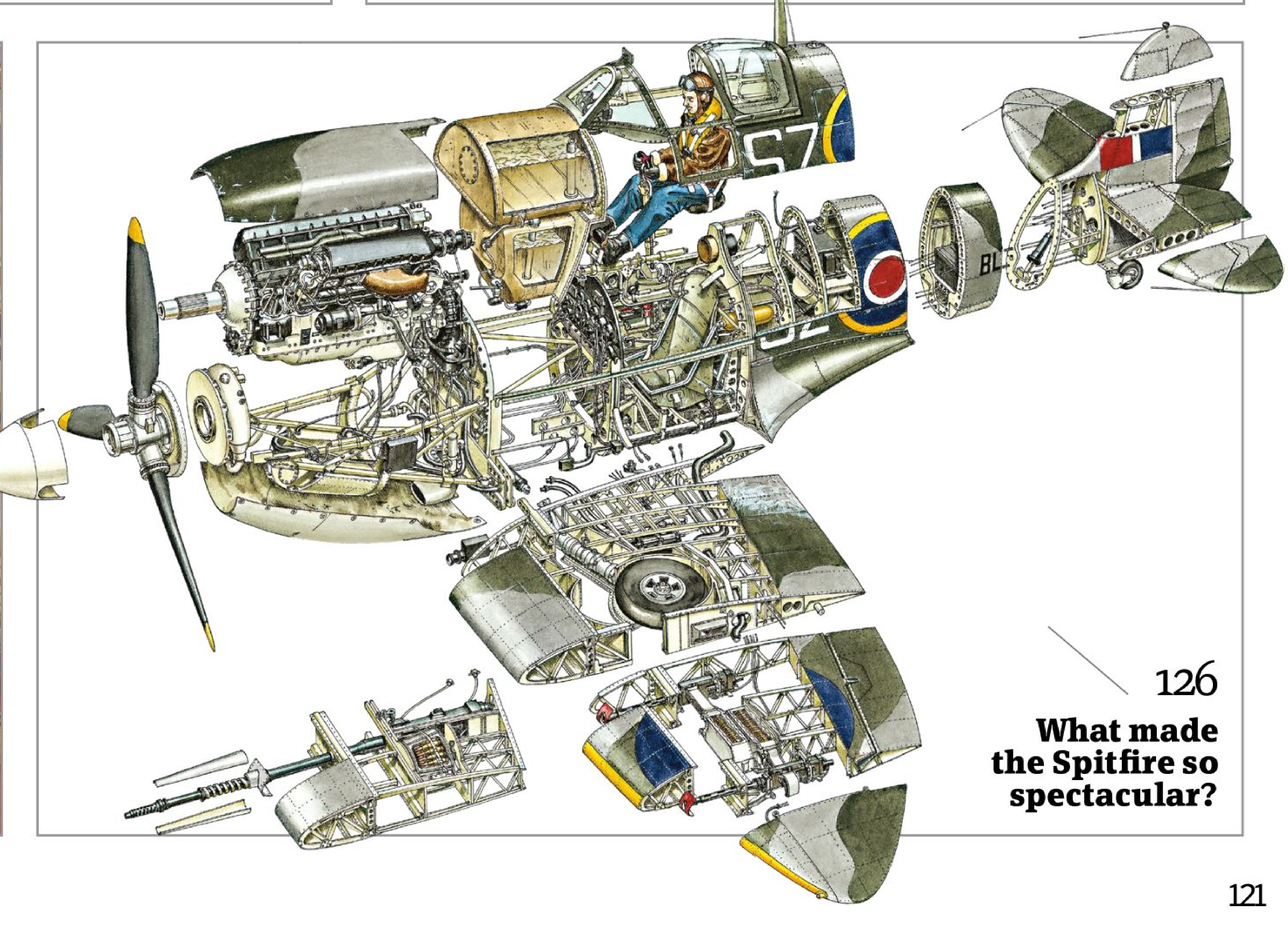
140

Building the dome of Florence Cathedral



136

Inside Henry VIII's royal residence



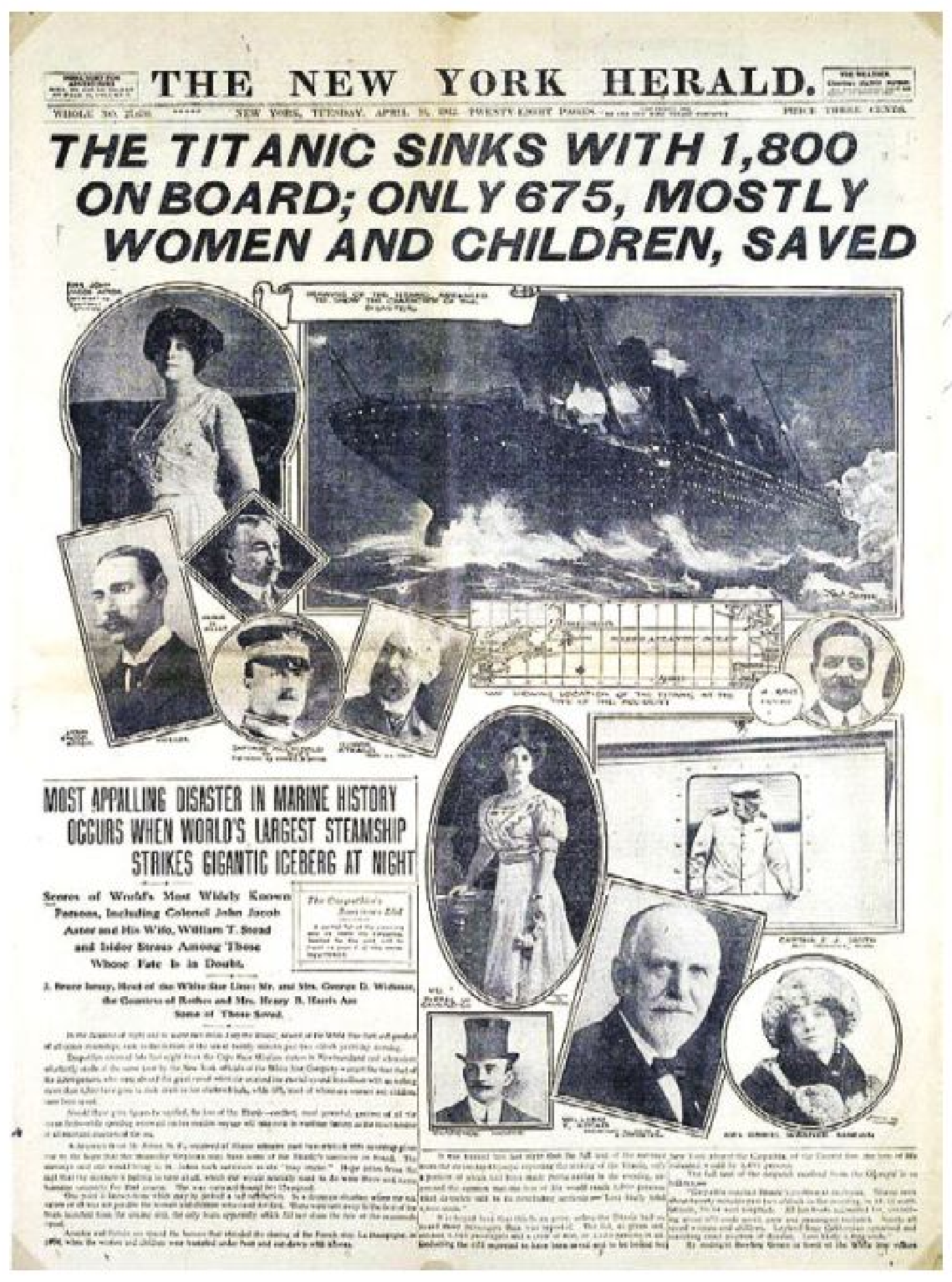
126

What made the Spitfire so spectacular?

The sinking of Titanic

Over a hundred years on, the story of how one of the world's greatest ships came to sink remains as mystifying as it is tragic. How It Works sets out to uncover what happened…

RMS Titanic was an Olympic-class passenger liner owned by British shipping company White Star Line and constructed at the Harland and Wolff shipyard in Belfast, Northern Ireland. Titanic was the largest ship in its class, along with its sister ship the Olympic, and was capable of holding over 2,000 people. Its maiden voyage from Southampton, UK, to New York began on 10 April 1912. However, four days into crossing the Atlantic the ship glanced an iceberg and sank within three hours, resulting in one of the worst maritime tragedies in history. The remarkable story of how it sank is even more surprising considering some of the technological advances used on the ship, but despite being one of the most high-profile disasters ever, many mysteries around the actions of the senior officers on that fateful night remain unanswered and will likely stay so forever.

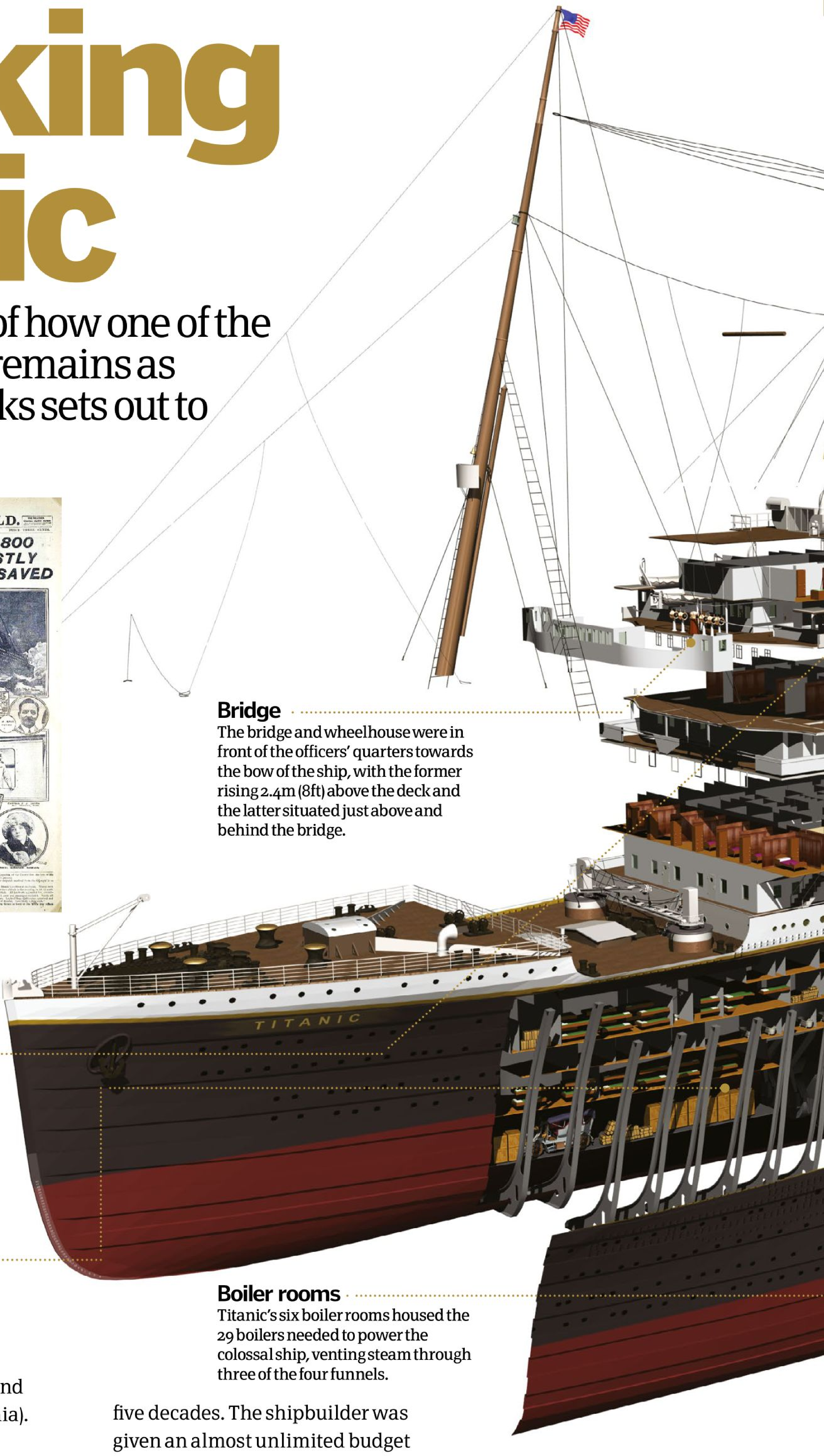


THE NEW YORK HERALD.

THE TITANIC SINKS WITH 1,800 ON BOARD; ONLY 675, MOSTLY WOMEN AND CHILDREN, SAVED

MOST APPALLING DISASTER IN MARINE HISTORY OCCURS WHEN WORLD'S LARGEST STEAMSHIP STRIKES GIGANTIC ICEBERG AT NIGHT

The front page of *The New York Herald* reporting on the tragedy



Bridge
The bridge and wheelhouse were in front of the officers' quarters towards the bow of the ship, with the former rising 2.4m (8ft) above the deck and the latter situated just above and behind the bridge.

Lifeboats
Titanic was equipped with enough lifeboats to save half the people on board, but due to the policy of 'women and children first' many of them departed half empty.

Workers
200 firemen, stokers and trimmers were needed to keep the furnaces burning. Of these, only a handful survived the sinking of the ship.

Boiler rooms
Titanic's six boiler rooms housed the 29 boilers needed to power the colossal ship, venting steam through three of the four funnels.

RMS Titanic was the second of three Olympic-class ships, the others being RMS Olympic (1910-1935) and RMS Britannic (sunk by a mine in 1916 after two years in service). For their time they were the largest ocean-liners in operation, and by far the biggest vessels in White Star Line's 1912 fleet of 29 ships. The three were all but identical in design save for a few very minor differences – mostly adjustments to Titanic to make it more luxurious for first-class passengers. They were built as a result of a rivalry between White Star Line and Cunard Line, the latter of which had just produced the fastest passenger ships around (the Lusitania and Mauretania). However, White Star Line's chairman, J Bruce Ismay, decided in 1907 to focus on size rather than speed, culminating in the building of these three behemoths.

The ships were constructed at Harland and Wolff in Belfast, which had been contracted to build ships for White Star Line for the previous five decades. The shipbuilder was given an almost unlimited budget to spend on the project and, by the end, Titanic and Olympic carried a combined cost of approximately £3 million ($4.75 million). Construction of Titanic began on 22 March 1909, just a few months after her sister the Olympic. Over 1,500 men worked on the two

WHO'S WHO?

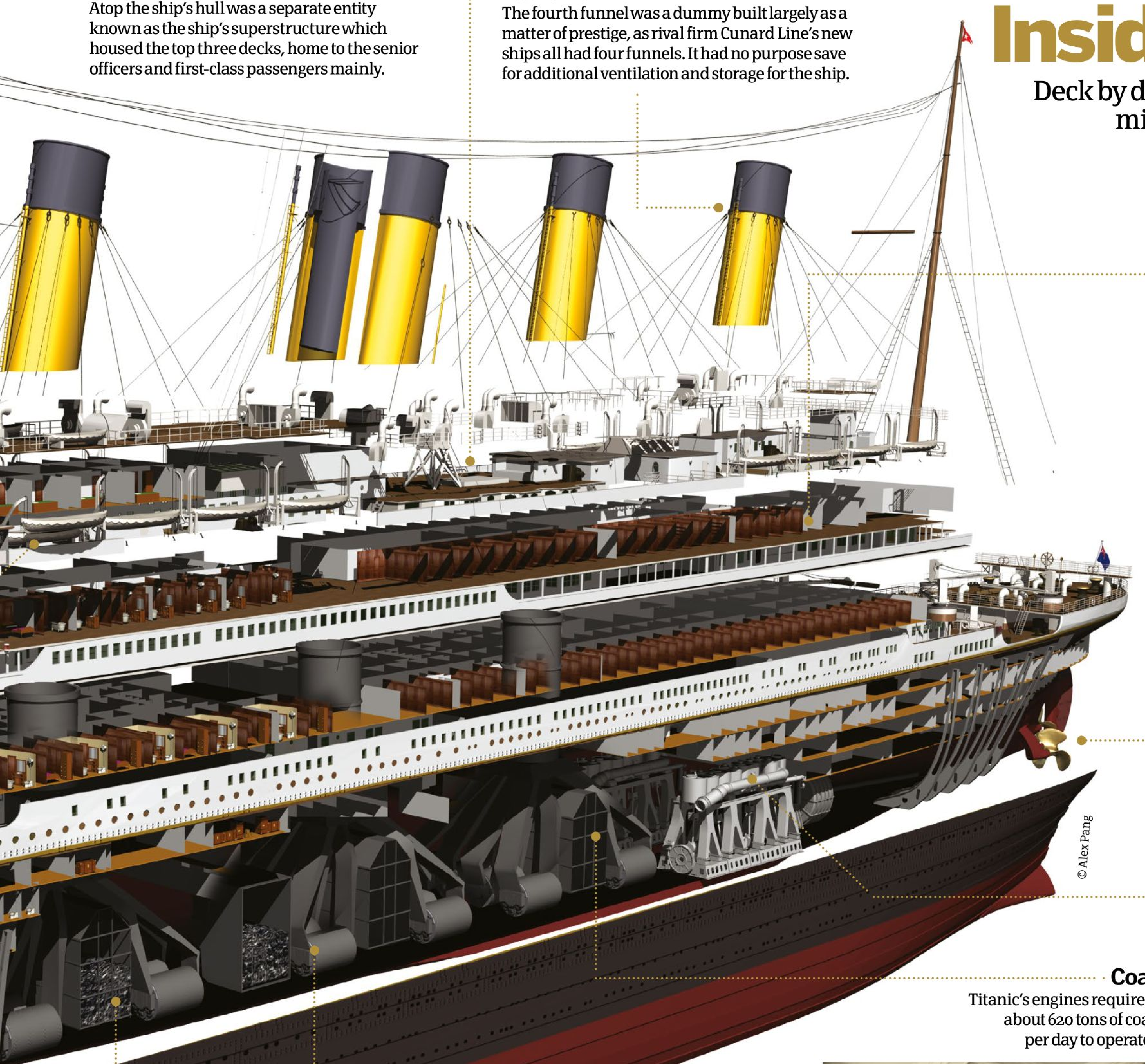
CAPTAIN SMITH 1850-1912

Edward John Smith began working for White Star Line in 1880 and it became tradition for him to skipper each of the White Star Line's new ships on their maiden voyage. He captained the Olympic in 1911 before Titanic in 1912. Despite being a bit of a maverick behind the wheel, he's often lauded as a hero after going down with the ship.

DID YOU KNOW? *RMS stands for Royal Mail Ship, an acronym used to designate vessels licensed to carry post by Royal Mail*

Inside Titanic

Deck by deck, take a look at how this mighty ship was put together



© Alex Pang

Superstructure
Atop the ship's hull was a separate entity known as the ship's superstructure which housed the top three decks, home to the senior officers and first-class passengers mainly.

Fourth funnel
The fourth funnel was a dummy built largely as a matter of prestige, as rival firm Cunard Line's new ships all had four funnels. It had no purpose save for additional ventilation and storage for the ship.

Decks
There were eight decks on Titanic. The uppermost housed the captain and his officers, and the next seven – lettered A through to G – housed passengers and crew in decreasing order of apparent social importance.

Horsepower
The entire engine system of Titanic was capable of producing over 33,500kW (45,000hp).

Engines
The engines had 159 furnaces that fired 29 boilers. 24 of these were double-ended, so they could be fed from both sides, and the rest were single-ended.

Coal
Titanic's engines required about 620 tons of coal per day to operate.

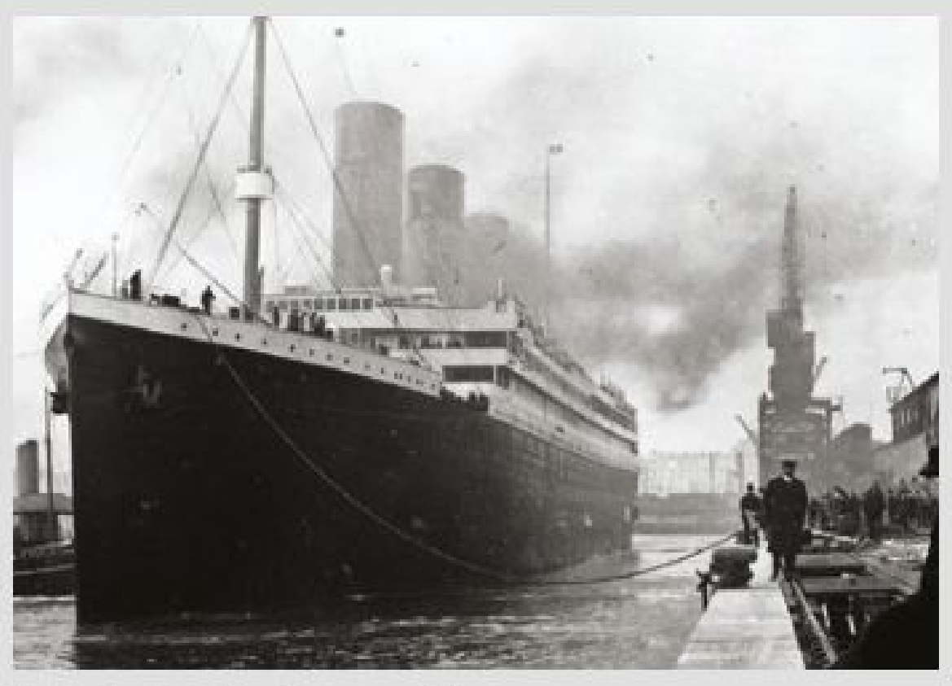
Furnaces
The furnaces were spread across six boiler rooms, each of which fed into three of the giant funnels. The fourth funnel was a dummy added for aesthetic purposes.

A shot of Titanic's first-class gymnasium

ships, with as many as eight dying during construction. In a development that would later prove crucial in the sinking of Titanic, the various steel plates of the vessel's hull were riveted together, as welding techniques were not yet sufficient in the early-20th century to hold together a ship of Titanic's magnitude.

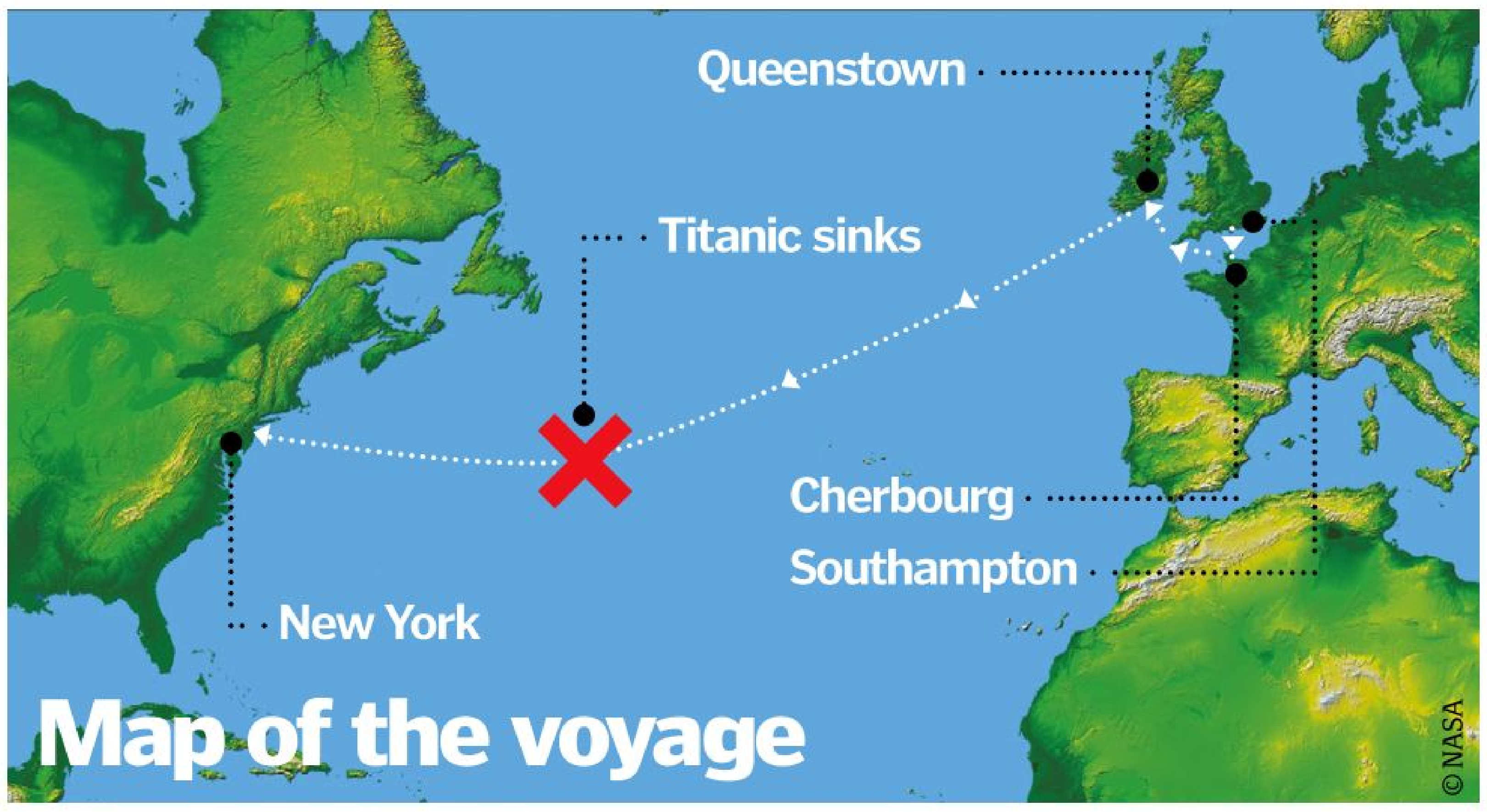
One of Titanic's most innovative features, and also possibly somewhat responsible for its sinking, was its engines. Its two twin four-cylinder engines each measured almost 12.2 metres (40 feet), the largest of their kind. These powered two three-blade propellers – one port and one starboard – at the stern. The propellers were a hefty 7.2 metres (23.5 feet) wide and rotated in opposite directions, 75 times per minute, to lessen vibrations. An additional third propeller was positioned between the two main propellers for added efficiency. It was smaller than the other two and used steam from their engines to rotate up to twice as fast. However, unlike the other two it was unable to rotate

The statistics…



RMS Titanic

Class: Olympic-class ocean-liner
Weight: 46,328 tons
Length: 269.1m (882.9ft)
Width: 28m (92ft)
Height (to top of funnels): 53.3m (175ft)
Top speed: 24 knots (44km/h; 28mph)
Decks: 8
Passenger capacity: 2,439
Crew capacity: 900



Map of the voyage

© NASA

backwards, which would ultimately prove detrimental when Titanic came face to face with an iceberg. Steering of the ship was largely handled by a mammoth, if somewhat cumbersome, 100-ton rudder.

Titanic was 11 storeys tall and as long as six city blocks. Its interior decks, especially the lower ones encased by the hull, were a maze of narrow passages and doors that only a few officers on board were able to competently navigate. Indeed, Second Officer Charles Lightoller recounted later that it took him 14 days aboard to be able to learn how to navigate from one end of the ship to the other. Considering Titanic sank just four days after it set off, with all the passengers on board never having set foot on the ship before, the complexity of its design brought obvious difficulties at the time of its sinking. Very few passengers in the steerage class were able to navigate their way successfully to the upper decks when Titanic began to sink. The story of how it sank though is a combination of poor design, bad luck and misdirection.

At 11.40pm on 11 April 1912, lookout Frederick Fleet spotted an iceberg directly ahead of Titanic and telephoned the bridge. Quartermaster Robert Hichens was ordered to change course. However, the turning procedure took up to 30 seconds owing to several factors, including the inability of the ship's third propeller to rotate backwards and the attempted deceleration of the ship, resulting in Titanic striking a glancing blow on the iceberg. Indeed, it may even have been better for the ship to speed up rather than attempt to slow down, as doing the latter lessened its turning angle. It is estimated that if Titanic had maintained its speed, it would have avoided the fatal iceberg by several metres.

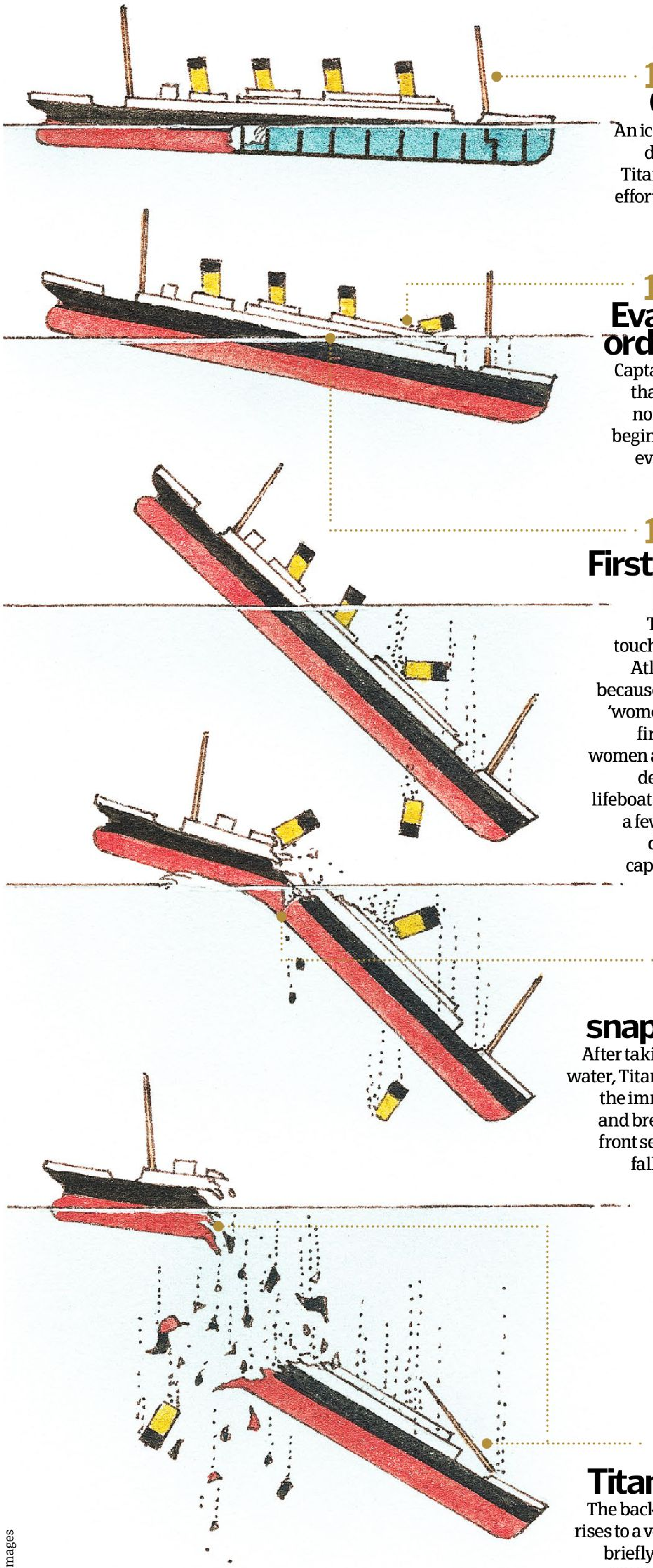
The impact with the iceberg produced a tear on the hull of Titanic more than 90 metres (300 feet) in length above the keel. The iron rivets used to keep the steel plates of the ship together were brittle and prone to snapping, while the plates themselves were weaker than modern steel due to impurities, meaning that they easily buckled under pressure from the iceberg. However, save for a loud bang near the point of impact there was little evidence of a collision throughout the majority of the ship apart from a slight shudder.

Water poured into the tear at a rate of about seven tons a second, flooding the Number 6 boiler room. Engineering staff worked to extinguish the furnaces and vent the boilers before they exploded upon contact with the icy cold water. The lower decks of Titanic were divided into 16 compartments, separated by bulkheads running the width of the ship. However, the bulkheads did not rise to the very top of the vessel, meaning that as water flooded each compartment it spilled into adjacent ones. Five compartments were breached by the iceberg; Titanic could only stay afloat with four flooded.

Due to the uneven rate of flooding, the ship listed five

Stages of sinking

In just over two and a half hours Titanic went from ship-shape to shipwreck



11.40pm
Collision
An iceberg is spotted directly ahead of Titanic and, despite efforts to avoid it, the ship strikes a glancing blow.

12.05am
Evacuation order given
Captain Smith is told that the vessel will not stay afloat and begins procedures to evacuate the ship.

12.45am
First lifeboat lowered
The first lifeboat touches down on the Atlantic. However, because of the policy of 'women and children first', and a lack of women and children on deck, many of the lifeboats leave with just a few dozen people, despite having a capacity of up to 65.

2.18am
Titanic snaps in half
After taking on too much water, Titanic succumbs to the immense pressure and breaks in two. The front section gradually falls to the seabed.

2.20am
Titanic sinks
The back half of the ship rises to a vertical position, briefly bobbing on the ocean's surface before plummeting to the depths.

© DK Images

5 TOP FACTS MARITIME DISASTERS

SS Sultana

1 The steamboat SS Sultana exploded and sank on 27 April 1865. Up to 1,800 of the 2,300 passengers on board died, the largest loss of life from a maritime disaster in US history.

MV Doña Paz

2 Up to 4,375 people died when the Philippine-registered passenger ferries MV Doña Paz and MT Vector collided on 20 December 1987, the deadliest peacetime ferry disaster.

Wilhelm Gustloff

3 On 30 January 1945, during WWII, German ship Wilhelm Gustloff was sunk by a Soviet Navy sub. Up to 9,400 died in the greatest ever loss of life in a maritime disaster.

Yamato

4 This Japanese warship was the largest battleship ever constructed. It was sunk on 7 April 1945 by US torpedo planes. Of the 2,778-man crew only 280 survived.

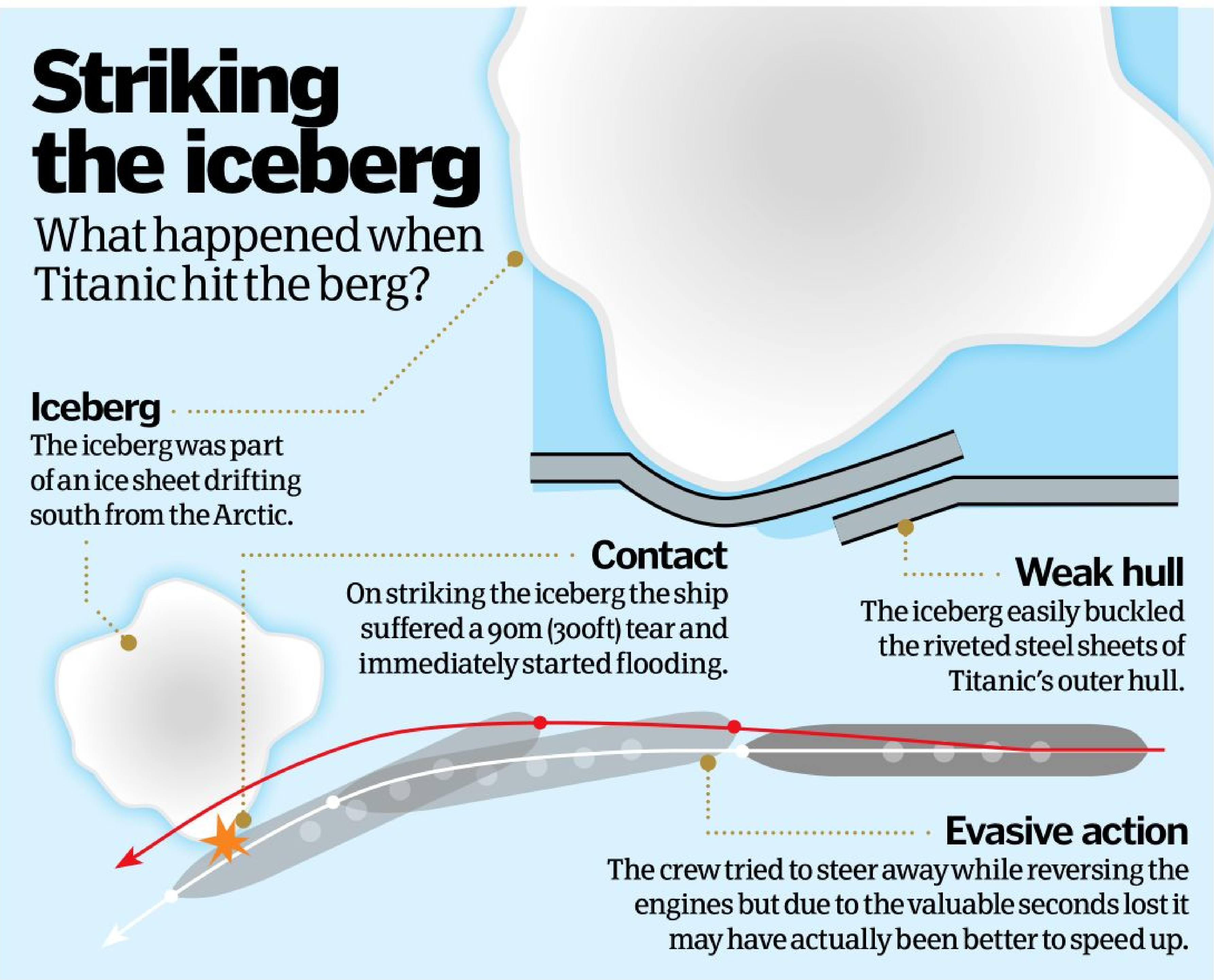
Costa Concordia

5 Costa Concordia ran aground on 13 January 2012 near the Isola del Giglio. More than 17 people are thought to have died when the ship was taken on an inappropriate course.

DID YOU KNOW? *Captain Smith narrowly averted crashing Titanic into the SS New York at the very start of its voyage*

Striking the iceberg

What happened when Titanic hit the berg?



Iceberg
The iceberg was part of an ice sheet drifting south from the Arctic.

Contact
On striking the iceberg the ship suffered a 90m (300ft) tear and immediately started flooding.

Weak hull
The iceberg easily buckled the riveted steel sheets of Titanic's outer hull.

Evasive action
The crew tried to steer away while reversing the engines but due to the valuable seconds lost it may have actually been better to speed up.

One of Titanic's lifeboats carrying far fewer passengers than it was designed to

degrees starboard just minutes after the collision. After 45 minutes, over 13,000 tons of water had been taken on board. The bilge pumps could only eject about 1,700 tons per hour, making it readily apparent that Titanic was doomed. The forward part of the ship gradually began to sink lower into the sea. Two hours on, the vessel was tilted forwards at an angle of ten degrees. This greatly increased the rate of flooding and, by 2.18am, the stress on the keel became too great, resulting in the ship snapping in two. The front half descended slowly to the bottom of the Atlantic but the back end rose to a vertical position in the water before crashing to the seabed at up to 48 kilometres (30 miles) per hour.

There were 2,206 passengers and crew on board Titanic. Of these, only 711 survived, despite the 20 lifeboats having a combined capacity of 1,178. There are several factors to blame, which include an inadequate number of lifeboats (although above the legal number for ships in 1912), poorly executed orders, lack of a ship-wide announcement system and inadequate information given to passengers. Indeed, up until the final hour many on board were convinced the ship would not sink. The high-profile sinking of Titanic sparked a complete overhaul of sailing safety measures, and a raft of changes were put in place to prevent such a disaster from occurring again. With the sinking of the Costa Concordia in January 2012, however, it's clear that, even over 100 years after this great disaster, there are still many lessons to be learned.

Interview
Greg Ward

We speak to the author of The Rough Guide To The Titanic to find out his thoughts on one of the greatest peacetime maritime disasters in history

How It Works: How did you become so interested in Titanic?
Greg Ward: I've written lots of books over the years, including history books, but my interest in Titanic came from my mother-in-law. She's a film professor and she organised a conference for James Cameron's *Titanic* movie in 1999 that I went along to, and after that I got very interested in Titanic. The most interesting for me is why Titanic looms so large in popular culture, and why the anniversary is such a big deal. It's a fascinating thing to consider, and it sort of goes beyond the ship itself.

HIW: What was the biggest challenge when researching?
GW: There's been so much written about Titanic, so there's a basic story out there. However, I came with a fairly fresh view on it so I didn't have any preconceived ideas about the story. One thing you find is that so many people have a particular axe to grind, and there are all sorts of controversies and issues and debates that people like to take sides on and run with. The challenge was to realise there were so many different stories with varying information that you just had to accept there are some things we don't know about the night Titanic sank. It's a disaster that happened in the middle of the night in the North Atlantic out of sight of the world.

HIW: What do you feel were the main factors that led to Titanic hitting an iceberg?
GW: There were two big inquiries after the event, first in America and then Britain, which overlap with people who testified in both. They came to a similar conclusion, which the British one put fairly succinctly in that Titanic hit the iceberg because it was going too fast and couldn't get out of the way, as obvious as it sounds. They said the captain, E J Smith, was pushing the ship too hard. Nobody at the time realised that was such a danger, and now anyone who caused the same event would be guilty of gross negligence. I think it's fascinating that the biggest and most advanced ship on the sea should be the one to hit an iceberg.

HIW: Why is the story of Titanic blurred in fact and fiction?
GW: Most of the survivors did not reach New York for three days after the disaster. At that point everybody in the world had heard Titanic had sunk, but there had been no details of what actually happened. The newspapers had to fill the news so they basically made things up or went with what they assumed must have happened. Other stories were based on small anecdotes or isolated incidents. For example, the story of the band playing *Nearer, My God, To Thee* as the ship went down came from just one particular survivor who said it was the last thing she saw, but she left on the first lifeboat 90 minutes before the ship sank. It's unlikely they kept playing till the bitter end as is often reported.

HIW: Have we learned any lessons from the Titanic?
GW: I watched a documentary about the sinking of the Costa Concordia recently, and there was footage of this stewardess saying everything is all right and there's no need for alarm while the ship was going down, and that passengers should return to their cabins. It's quite chilling to see that, even after Titanic, people are still not kept informed during such a disaster. The instinctive reaction of the Titanic authorities was that it's best to prevent panic, and it's scary to think it's exactly the same 100 years on.

The Rough Guide To The Titanic is available for £9.99/$14.99 from **www.roughguides.com**.

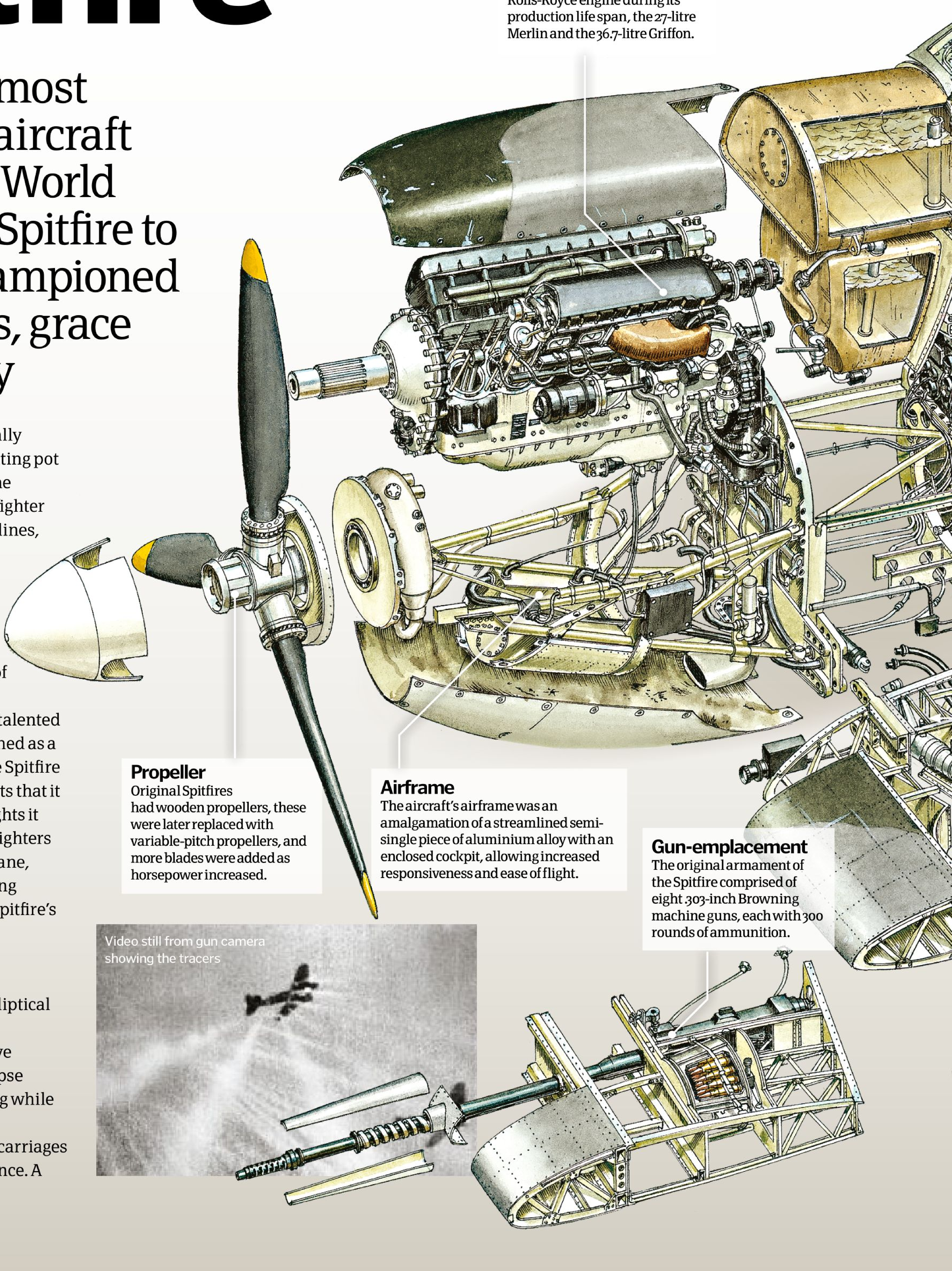
Supermarine Spitfire

Arguably the most iconic fighter aircraft of the Second World War, the RAF Spitfire to this day is championed for its prowess, grace and versatility

Designed in the technologically fervent and innovatory melting pot of the Second World War, the Supermarine Spitfire became the fighter plane of the times. With its simple lines, elegant frame and superb aerodynamics, the Spitfire was to live on in the minds of generations during the war and for decades to come.

The Spitfire was the brainchild of aeronautical engineer Reginald Mitchell, who led a dedicated and talented team of designers. Originally planned as a short-range air-defence fighter, the Spitfire was built for speed and agility, traits that it was to need in the explosive dogfights it was to partake in as it met enemy fighters and bombers. Building a fighter plane, though, is more complex than listing desirable traits however, and the Spitfire's construction is a balletic series of compromises between weight, aerodynamics and firepower.

The frame of a spitfire with its elliptical wings is one of its most defining characteristics, casting a distinctive silhouette against the sky. The ellipse shaping was used to minimise drag while having the necessary thickness to accommodate the retracted undercarriages and the guns required for self defence. A



Rolls-Royce Vee-12 engine
The Spitfire utilised two variant of Rolls-Royce engine during its production life span, the 27-litre Merlin and the 36.7-litre Griffon.

Propeller
Original Spitfires had wooden propellers, these were later replaced with variable-pitch propellers, and more blades were added as horsepower increased.

Airframe
The aircraft's airframe was an amalgamation of a streamlined semi-single piece of aluminium alloy with an enclosed cockpit, allowing increased responsiveness and ease of flight.

Gun-emplacement
The original armament of the Spitfire comprised of eight 303-inch Browning machine guns, each with 300 rounds of ammunition.

Video still from gun camera showing the tracers

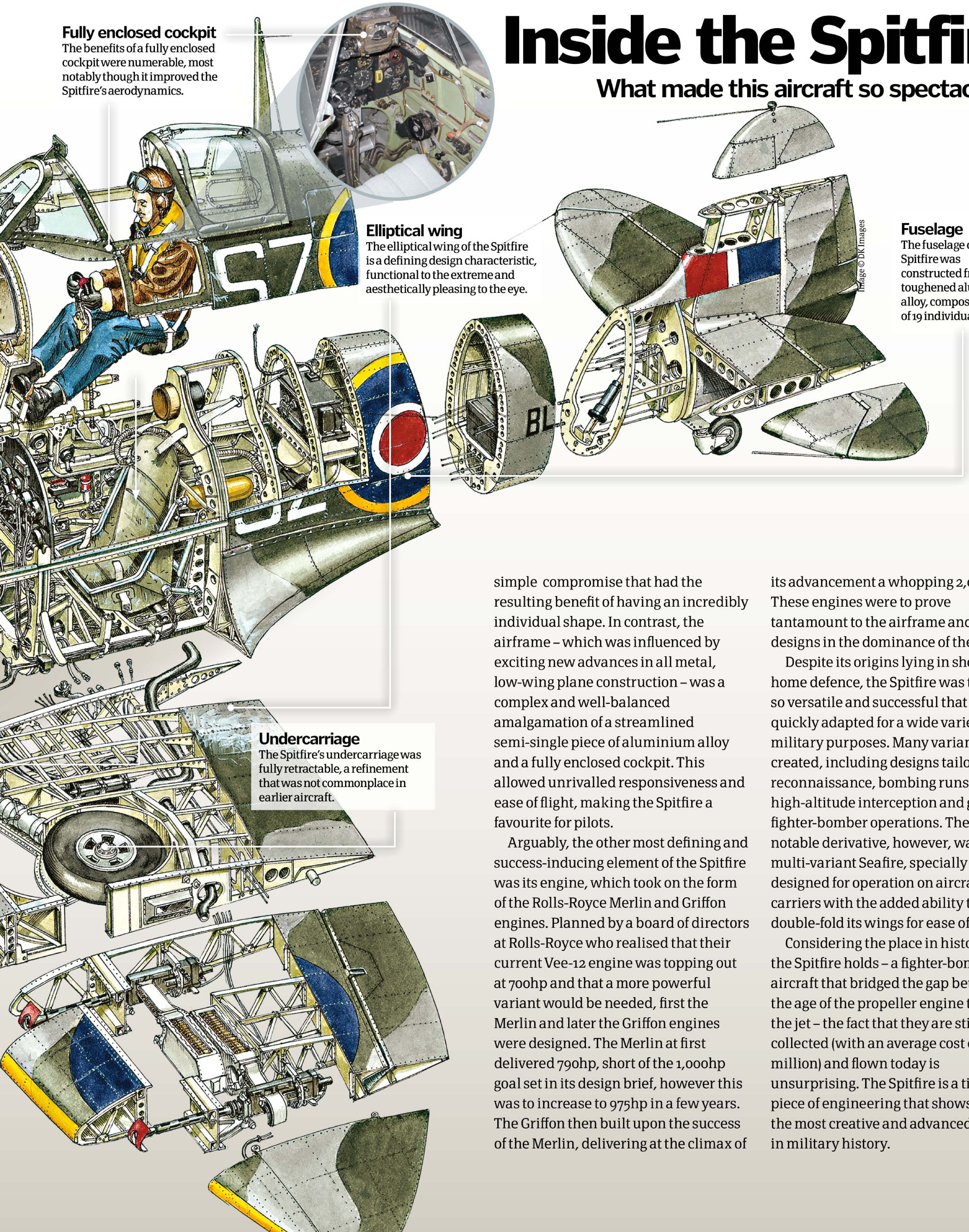
THE STATS
RAF SPITFIRE

MAX SPEED **450mph** RANGE 400 miles LENGTH **32ft 11ins**
WINGSPAN 36ft 11in ARMAMENT **20mm cannon x4**

DID YOU KNOW? *By 1939, approximately ten per cent of all Spitfires had been lost as a result of training accidents*

Inside the Spitfire

What made this aircraft so spectacular?



Fully enclosed cockpit
The benefits of a fully enclosed cockpit were numerable, most notably though it improved the Spitfire's aerodynamics.

Elliptical wing
The elliptical wing of the Spitfire is a defining design characteristic, functional to the extreme and aesthetically pleasing to the eye.

Fuselage
The fuselage of the Spitfire was constructed from toughened aluminium alloy, composing of 19 individual frames.

Undercarriage
The Spitfire's undercarriage was fully retractable, a refinement that was not commonplace in earlier aircraft.

Image © DK Images

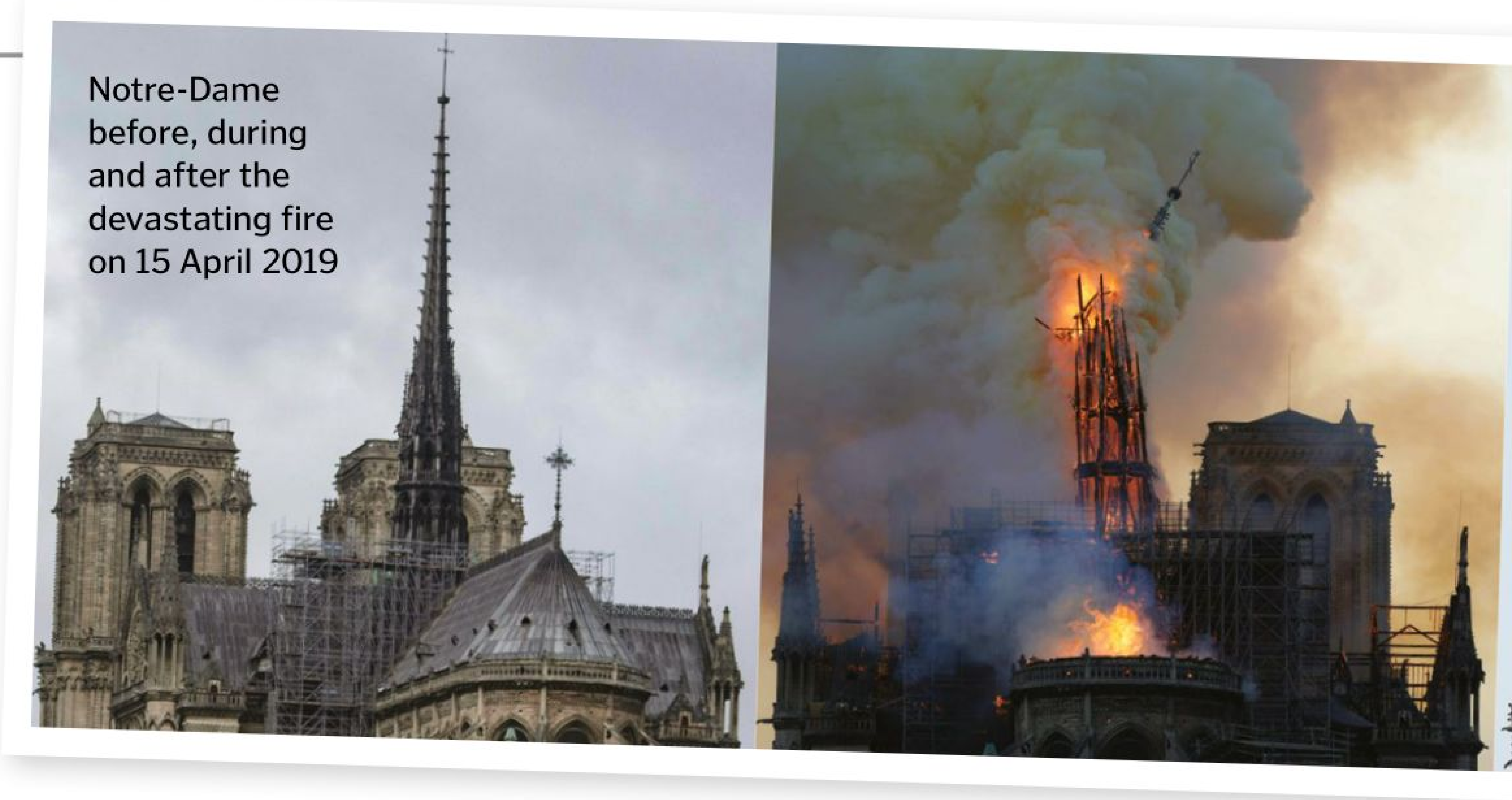
simple compromise that had the resulting benefit of having an incredibly individual shape. In contrast, the airframe – which was influenced by exciting new advances in all metal, low-wing plane construction – was a complex and well-balanced amalgamation of a streamlined semi-single piece of aluminium alloy and a fully enclosed cockpit. This allowed unrivalled responsiveness and ease of flight, making the Spitfire a favourite for pilots.

Arguably, the other most defining and success-inducing element of the Spitfire was its engine, which took on the form of the Rolls-Royce Merlin and Griffon engines. Planned by a board of directors at Rolls-Royce who realised that their current Vee-12 engine was topping out at 700hp and that a more powerful variant would be needed, first the Merlin and later the Griffon engines were designed. The Merlin at first delivered 790hp, short of the 1,000hp goal set in its design brief, however this was to increase to 975hp in a few years. The Griffon then built upon the success of the Merlin, delivering at the climax of its advancement a whopping 2,035hp. These engines were to prove tantamount to the airframe and wing designs in the dominance of the Spitfire.

Despite its origins lying in short-range home defence, the Spitfire was to prove so versatile and successful that it was quickly adapted for a wide variety of military purposes. Many variants were created, including designs tailored for reconnaissance, bombing runs, high-altitude interception and general fighter-bomber operations. The most notable derivative, however, was the multi-variant Seafire, specially designed for operation on aircraft carriers with the added ability to double-fold its wings for ease of storage.

Considering the place in history that the Spitfire holds – a fighter-bomber aircraft that bridged the gap between the age of the propeller engine to that of the jet – the fact that they are still collected (with an average cost of £1.4 million) and flown today is unsurprising. The Spitfire is a timeless piece of engineering that shows some of the most creative and advanced efforts in military history.

Rebuilding Notre-Dame


Notre-Dame before, during and after the devastating fire on 15 April 2019

This won't be the first time Paris's famous cathedral has been restored to its former glory

As the inferno engulfed the 850-year-old Gothic Notre-Dame cathedral on 15 April, the world was watching. The despair of Parisians was simulcast to millions of screens across the planet, with the tragedy trending on Twitter. But why is this medieval building a world-renowned landmark?

Notre-Dame (meaning 'Our Lady') is far more than a setting for holiday snaps and postcards. It's an icon of Gothic architecture that houses many amazing artworks and holy relics. While the French kings preferred to be crowned at Reims, Notre-Dame has been witness to many historic events.

Not that time has always been kind to the cathedral. During the French Revolution, rebels destroyed many of its statues, melted down its bells, and after a brief stint using it as a secular 'Temple of Reason', turned it into a warehouse.

Later in the 19th century, when Paris's medieval ruins were being bulldozed, French author Victor Hugo argued they should be preserved. As well as publishing a pamphlet called *War on the Demolishers!*, he wrote *The Hunchback of Notre-Dame* – simply titled *Notre-Dame* in France.

The story of Quasimodo the cathedral bell-ringer captured the French public's imagination. This led to a nearly 20-year restoration of Notre-Dame, starting in 1844. While architect Eugène Viollet-le-Duc went to great pains to repair the damage, he was later criticised for making his own modifications and using more modern materials, such as concrete, to renovate the spire.

Despite further repairs in 1991, the cathedral was in trouble before this year's fire broke out. Ravaged by pollution, the Archdiocese of Paris believed it would cost over £141 million to restore Notre-Dame. While the fire caused even more damage, an international funding effort quickly began to help raise the cathedral from the ashes. Nearly £780 million was donated in the first 48 hours following the fire.

Craftspeople that helped repair York Minster, which was built 15 years after Notre-Dame, could help with the reconstruction

© Alamy

Notre-Dame 2.0

French President Emmanuel Macron has vowed to rebuild Notre-Dame in time for the Paris Olympics in 2024. But could this be possible? After a fire in 1984, it took four years to repair the damage at the similar-sized York Minster in England.

Of course, many of those who worked on York Minster could lend their expertise to Notre-Dame. New technology could also play a role. Laser scans of Notre-Dame from 2015 contain 1 billion data points. These could be used as a high-resolution 3D blueprint to help reconstruct the medieval structure.

A bigger problem may be finding medieval materials. 5,000 oak trees were used to build the original timber roof. In the 19th century, restorers carefully researched the original location of the ancient quarries used for Notre-Dame's masonry. But with the modern geography of Paris transformed, some of these may now prove very hard to find or impossible to access.

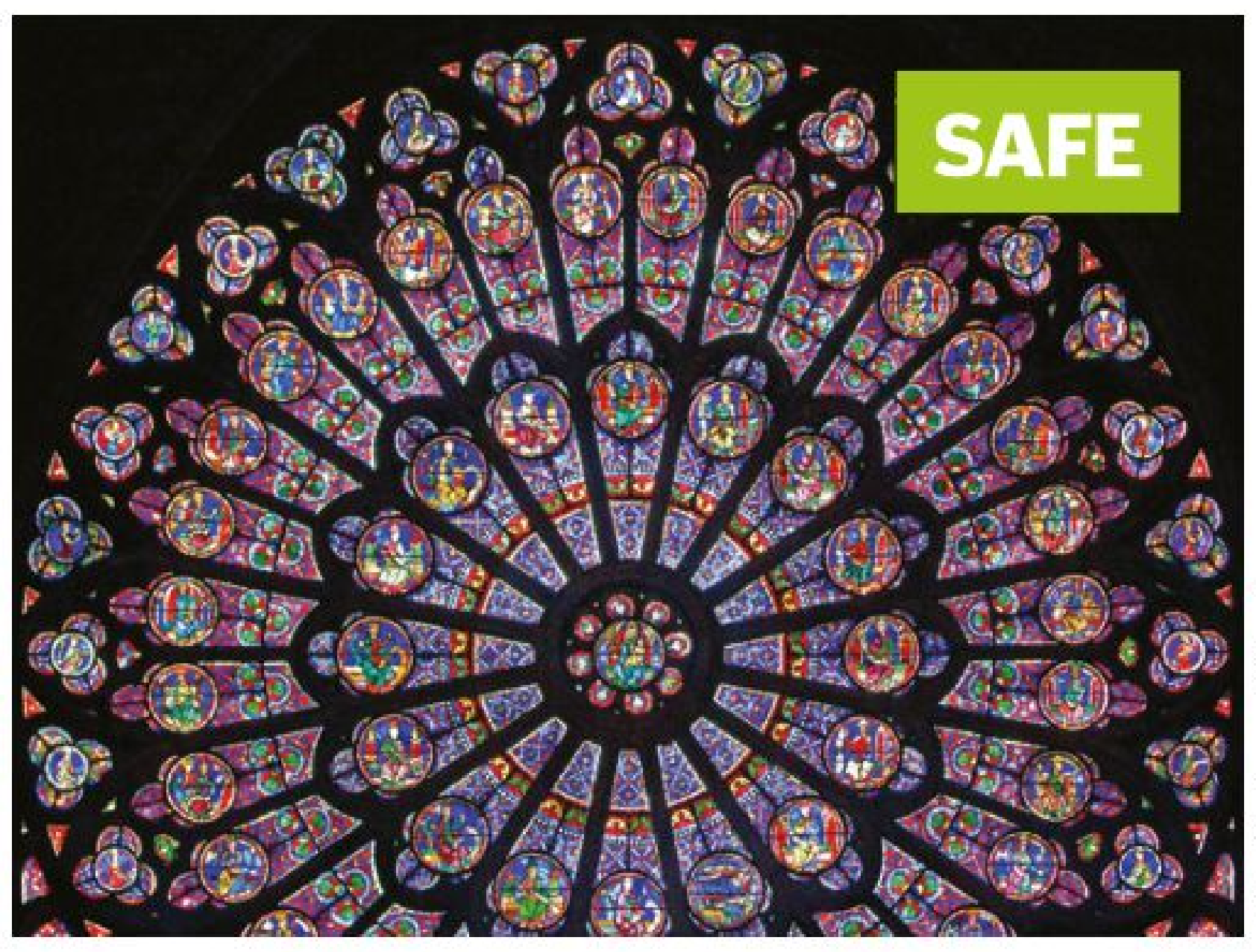
© Getty

York Minster's lead joiner Geoff Brayshaw poses above the roof of the South Transept

The cathedral's treasure trove

Crown of Thorns

The most precious object in Notre-Dame's collection is believed to have been worn by Jesus Christ. Given to Louis IX in 1238, the thorns are preserved in a reliquary made of gold and crystal.



© Julie Anne Workman

The rose windows

The cathedral's spectacular stained-glass rose windows are made up of petal-shaped panes, each depicting Bible scenes. The west window is the oldest, from 1125, while the south is a huge 12.9 metres in diameter.

© Eric Chan

The great organ

The largest organ in France, it was rebuilt in the 19th century, but some of its 8,000 pipes date from the 1200s. Organist Louis Vierne played 1,750 concerts before fulfilling his dream of dying at the instrument in 1937.

The relics of Saint Denis and Saint Geneviève

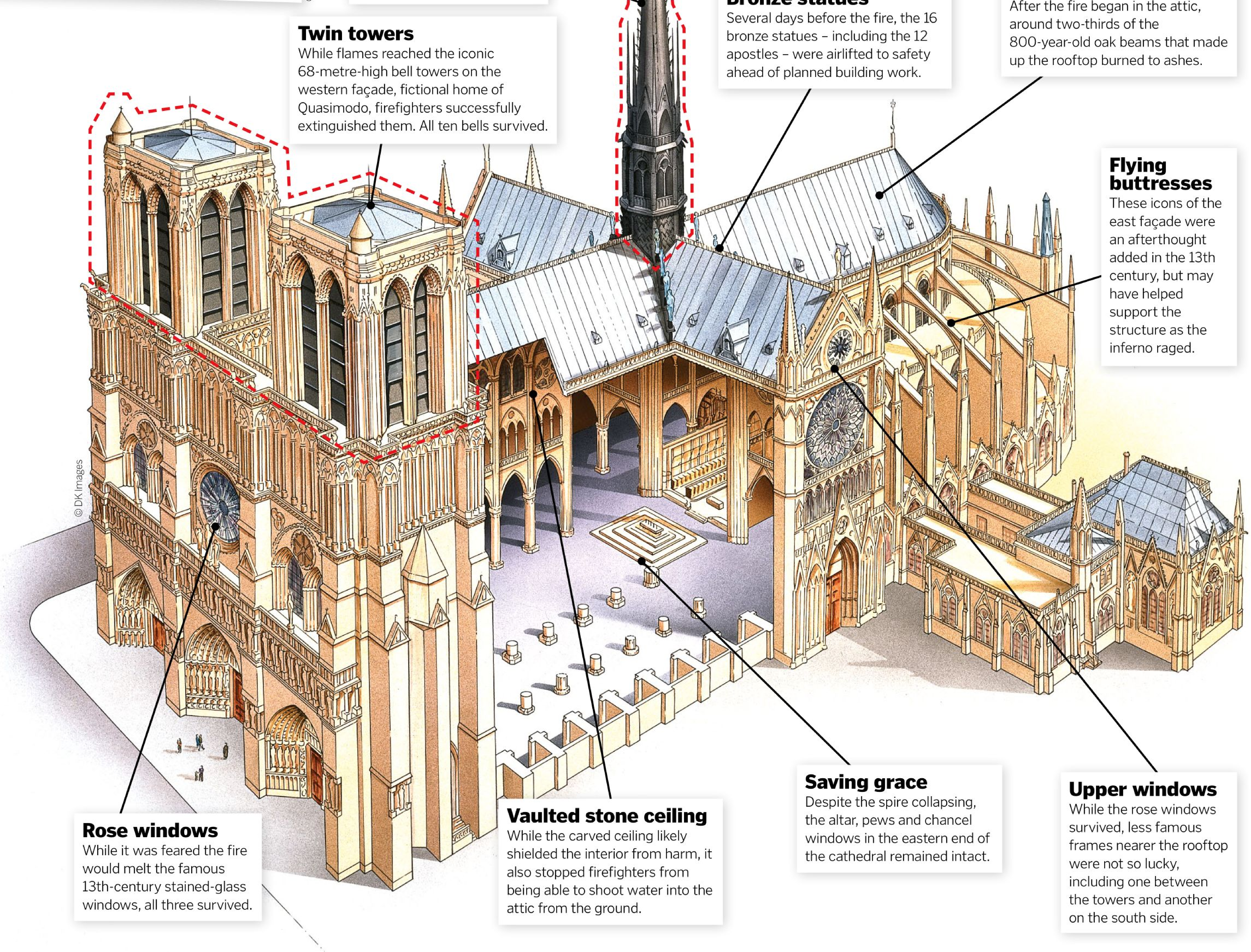
Bones, teeth and hair belonging to the patron saints of Paris were destroyed when the spire collapsed. An archbishop had placed them there in 1935 to protect the cathedral.

DID YOU KNOW? *Some 200,000 bees, living on the cathedral's rooftop hives since 2013, survived the fire*

© Getty

What was damaged?

The blaze came close to bringing down the medieval marvel


© DK Images

How the fire spread
While it was feared the blaze could level the landmark, the flames were mostly confined to the rooftop. Though the exact cause is still being investigated, the fire began in the cathedral attic. This then ripped through the crisscross of 800-year-old wooden beams, which burned to ash. Possibly stoked by sawdust in the attic, the fire also caused the steeple to collapse. Notre-Dame's vaulted stone ceiling shielded the cathedral's interior – including its famous rose windows – from harm. But this masonry also stopped firefighters from being able to shoot water into the attic from the ground.

Gothic spire
Though the original medieval steeple was dismantled in the 1780s, the destruction of the 19th-century reproduction stunned onlookers.

Twin towers
While flames reached the iconic 68-metre-high bell towers on the western façade, fictional home of Quasimodo, firefighters successfully extinguished them. All ten bells survived.

Bronze statues
Several days before the fire, the 16 bronze statues – including the 12 apostles – were airlifted to safety ahead of planned building work.

Irreplaceable roof
After the fire began in the attic, around two-thirds of the 800-year-old oak beams that made up the rooftop burned to ashes.

Flying buttresses
These icons of the east façade were an afterthought added in the 13th century, but may have helped support the structure as the inferno raged.

Rose windows
While it was feared the fire would melt the famous 13th-century stained-glass windows, all three survived.

Vaulted stone ceiling
While the carved ceiling likely shielded the interior from harm, it also stopped firefighters from being able to shoot water into the attic from the ground.

Saving grace
Despite the spire collapsing, the altar, pews and chancel windows in the eastern end of the cathedral remained intact.

Upper windows
While the rose windows survived, less famous frames nearer the rooftop were not so lucky, including one between the towers and another on the south side.

The rise, fall and resurrection of Notre-Dame

1163
FOUNDING FATHER
The cathedral's first stone is laid on Paris's Île de la Cité, with Pope Alexander III attending the ceremony.

1185
CALL TO ARMS
Heraclius, archbishop of Caesarea, calls for the Third Crusade from the still-unfinished cathedral.

1431
CROWNING ACHIEVEMENT
During the Hundred Years' War, ten-year-old Henry VI of England is also proclaimed ruler of France in Notre-Dame Cathedral.

1548
RELIGIOUS RIOTING
Rioting French Protestants – known as Huguenots – damage some of the statues in the Catholic cathedral.

1793
OFF WITH THEIR HEADS
Mobs loot the cathedral during the French Revolution and even decapitate 28 statues of biblical kings in a mock execution.

1804
ALL HAIL NAPOLEON
In a lavish ceremony at the cathedral, watched by a cheering crowd, Napoleon crowns himself emperor of the French.

1844
NOVEL COMEBACK
The popularity of Victor Hugo's *The Hunchback of Notre-Dame* prompts a major restoration of the cathedral.

1871
PARIS IS BURNING
During the Paris Commune insurrection, Notre-Dame is set alight, but it doesn't cause lasting damage.

1914
THE SKY IS FALLING
WWI sees the rise of aerial bombing, but Notre-Dame survives relatively unscathed – except for a hole in the roof.

Fossils

Discover life forms that lived millions or billions of years ago before being turned to stone

Extinction is a fact of life that, sooner or later, spells the end for all species. But dead doesn't mean forgotten. The evidence might have remained hidden for millions or even billions of years but, in the fifth century BCE, Greek philosopher Xenophanes discovered the fossils of sea creatures and recognised what they were.

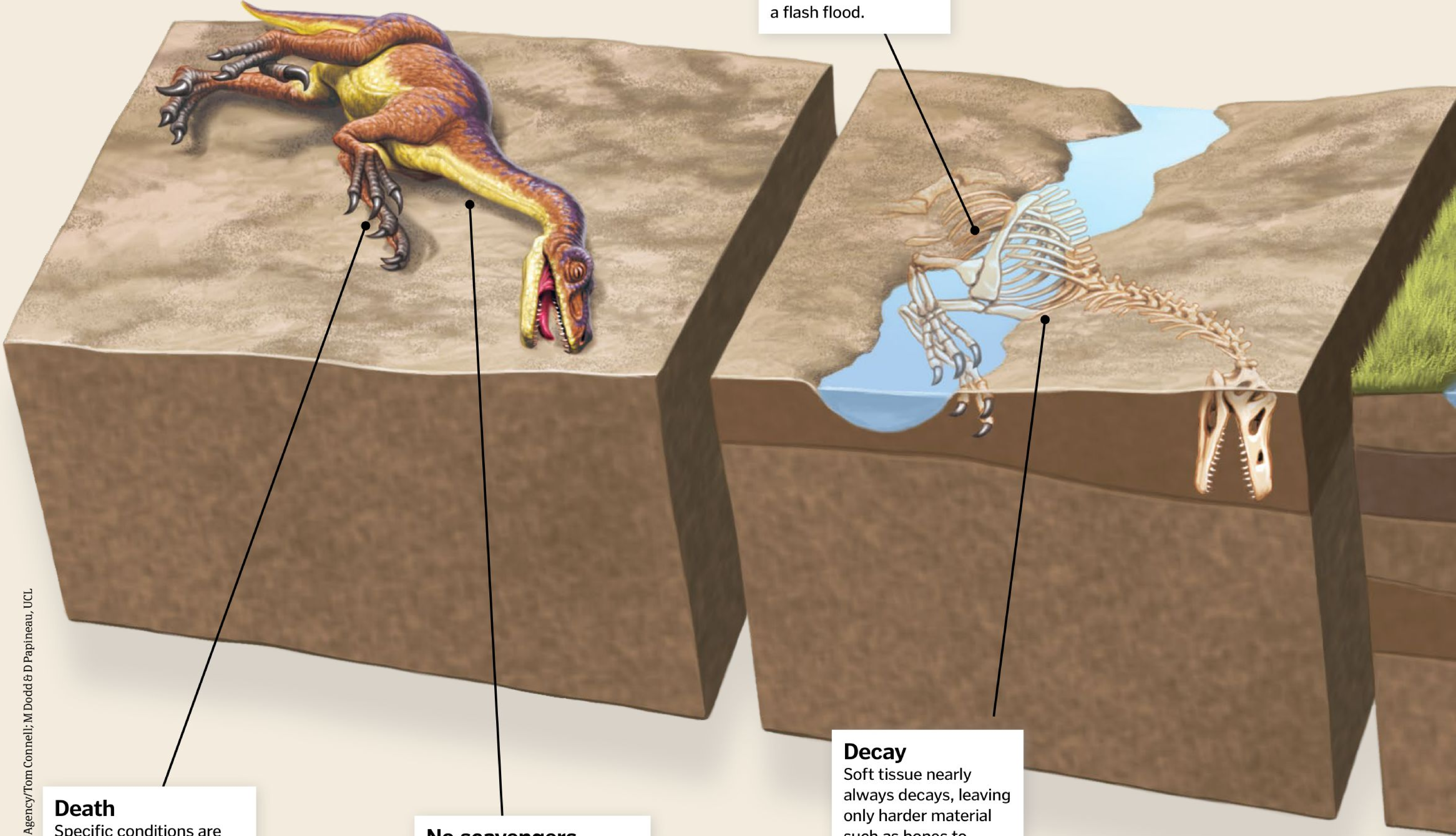
We'll look at exactly how it happens later, but put simply, a fossil was a living organism, which, following its death, turned to stone. And these records can teach us so much. Having found marine fossils on land, for example, Xenophanes was able to say with confidence that the sea once covered what was then dry land. Over the years, fossils have taught us a great deal about Earth's history, and the discoveries continue today.

For example, recent discoveries of fossils dating back to the dawn of our planet, when the Earth was an apparently inhospitable place, have fuelled speculation that life could have started on Mars at about the same time.

Mention fossils and many people think instantly of dinosaurs. These huge lizards might have left some of the largest, most impressive fossils, but they are not nearly the oldest, nor do they have a monopoly on providing a spectacle. The world of fossils is a varied one encompassing wonders as extraordinary as trilobites: large woodlouse-like creatures that crawled on the bed of tropical seas; brightly coloured petrified wood from long lost forests in Arizona; and coprolite – fossilised droppings.

The formation of fossils

How a living organism can be turned into stone and preserved for millions of years



Burial
Protection of the remains is assisted by rapid burial, perhaps by sediment carried by a flash flood.

Death
Specific conditions are required for fossil formation to occur; once dead, most organisms decompose completely.

No scavengers
For the remains to be fossilised they must not be destroyed by scavengers.

Decay
Soft tissue nearly always decays, leaving only harder material such as bones to fossilise, although creatures with exoskeletons can fossilise completely.

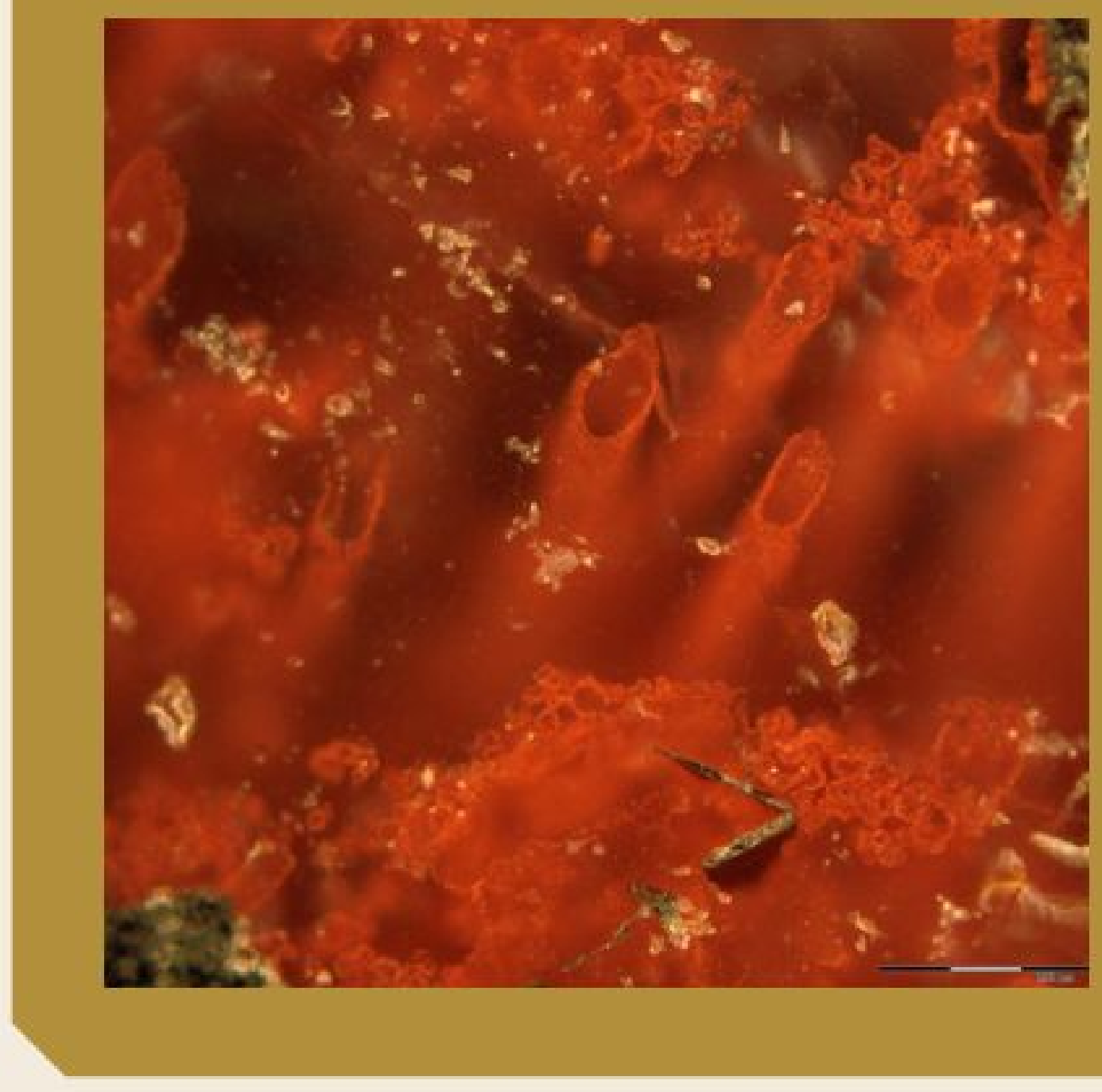
© Alamy; WIKI; Illustration by Art The Agency/Tom Connell; M Dodd & D Papineau, UCL.

DID YOU KNOW? *Small creatures such as insects can be found preserved in amber, the fossilised resin of pine*

Top five fossil discoveries

The oldest fossils

Scientists at UCL have announced the oldest fossils yet. The tube-like structures, found in Canada, are about 3.77 billion years old and grew around deep-sea vents.

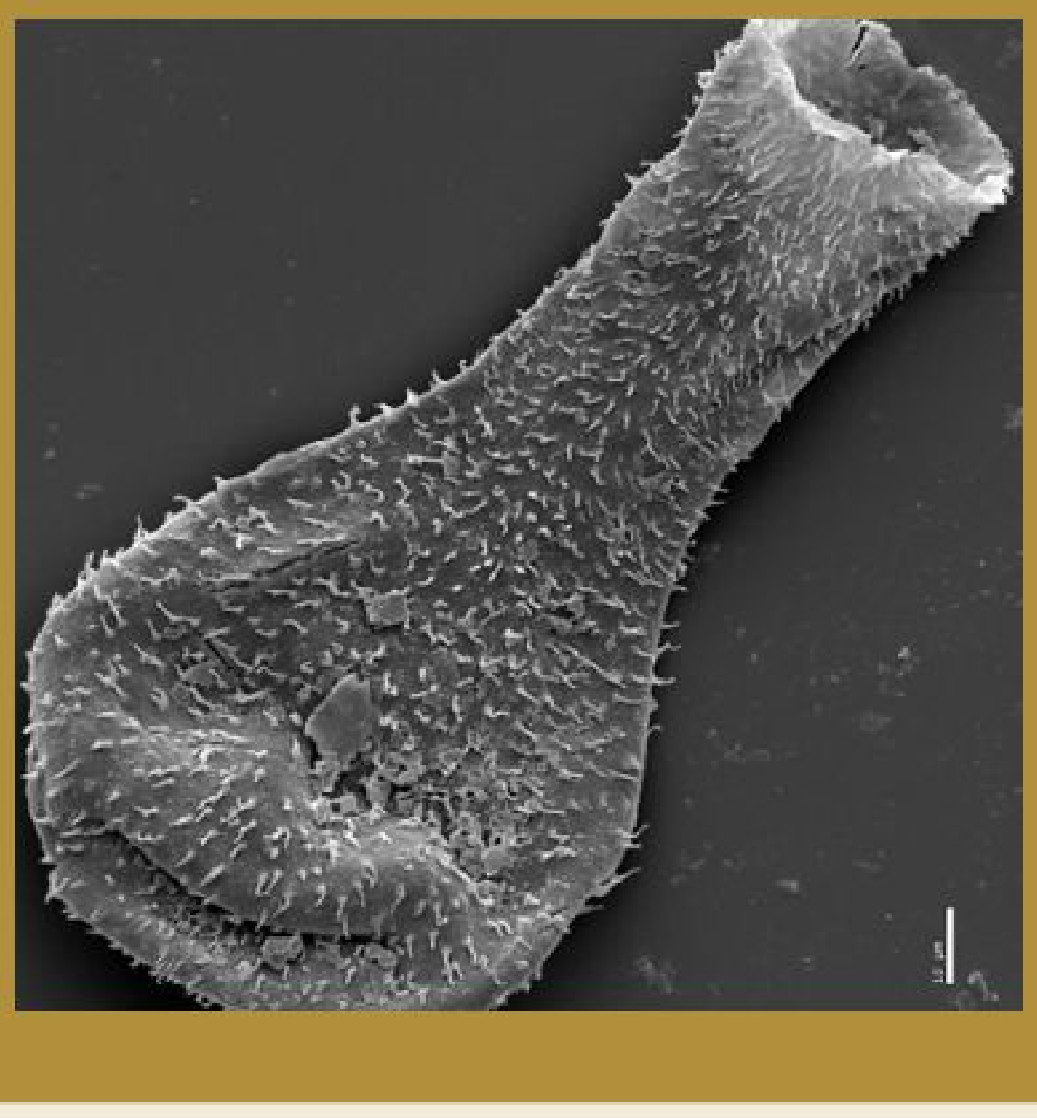


The largest fossil

Fossilised bones from Argentina represent the largest known dinosaur. The titanosaur was nearly 40 metres long, stood 20 metres tall, and weighed about 70 tons.

The smallest fossils

Not all fossils are massive; some are so small you need a microscope to see them. Marine microfossils known as Chitinozoa, for example, can be as little as 0.05mm long.

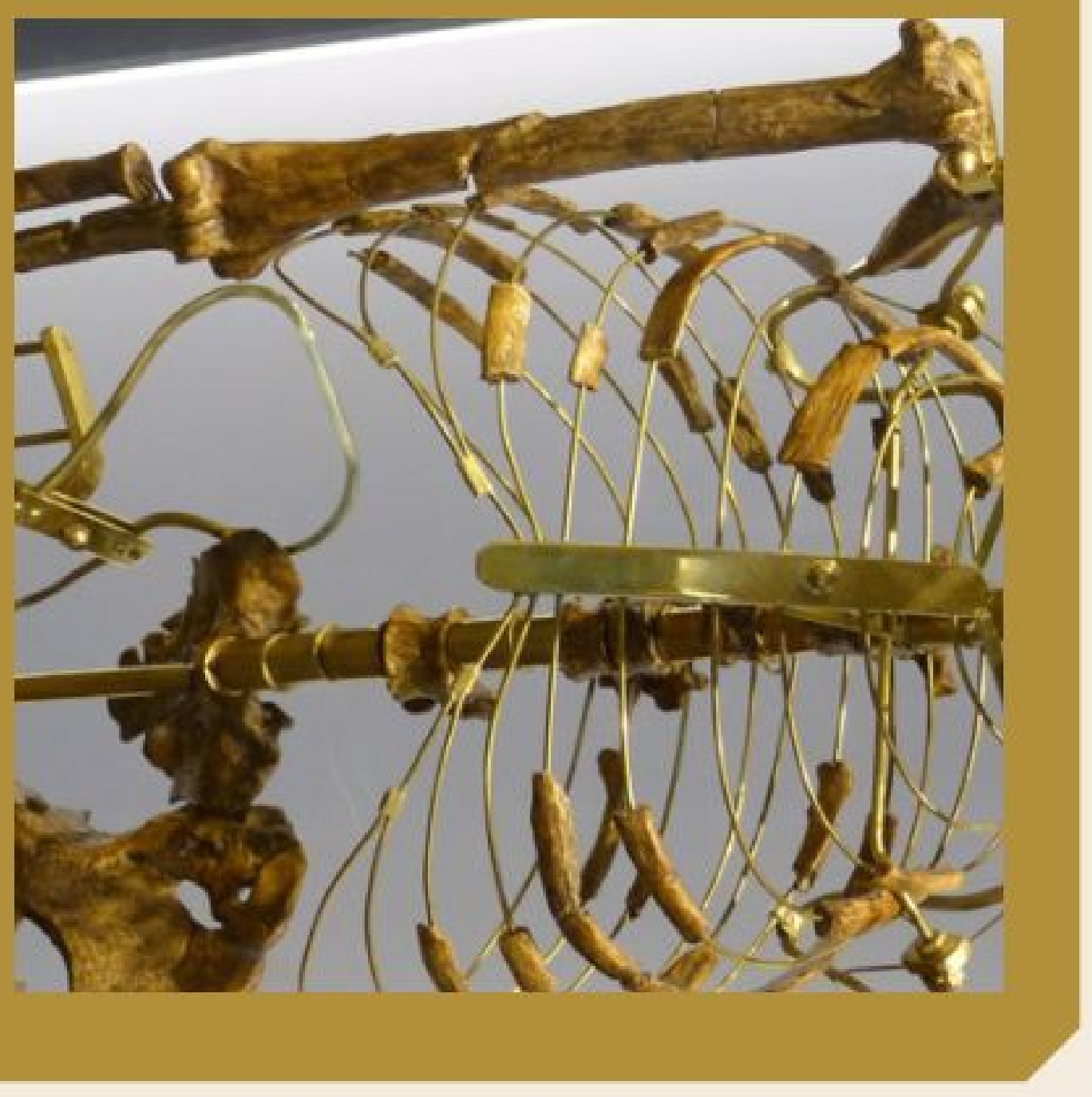


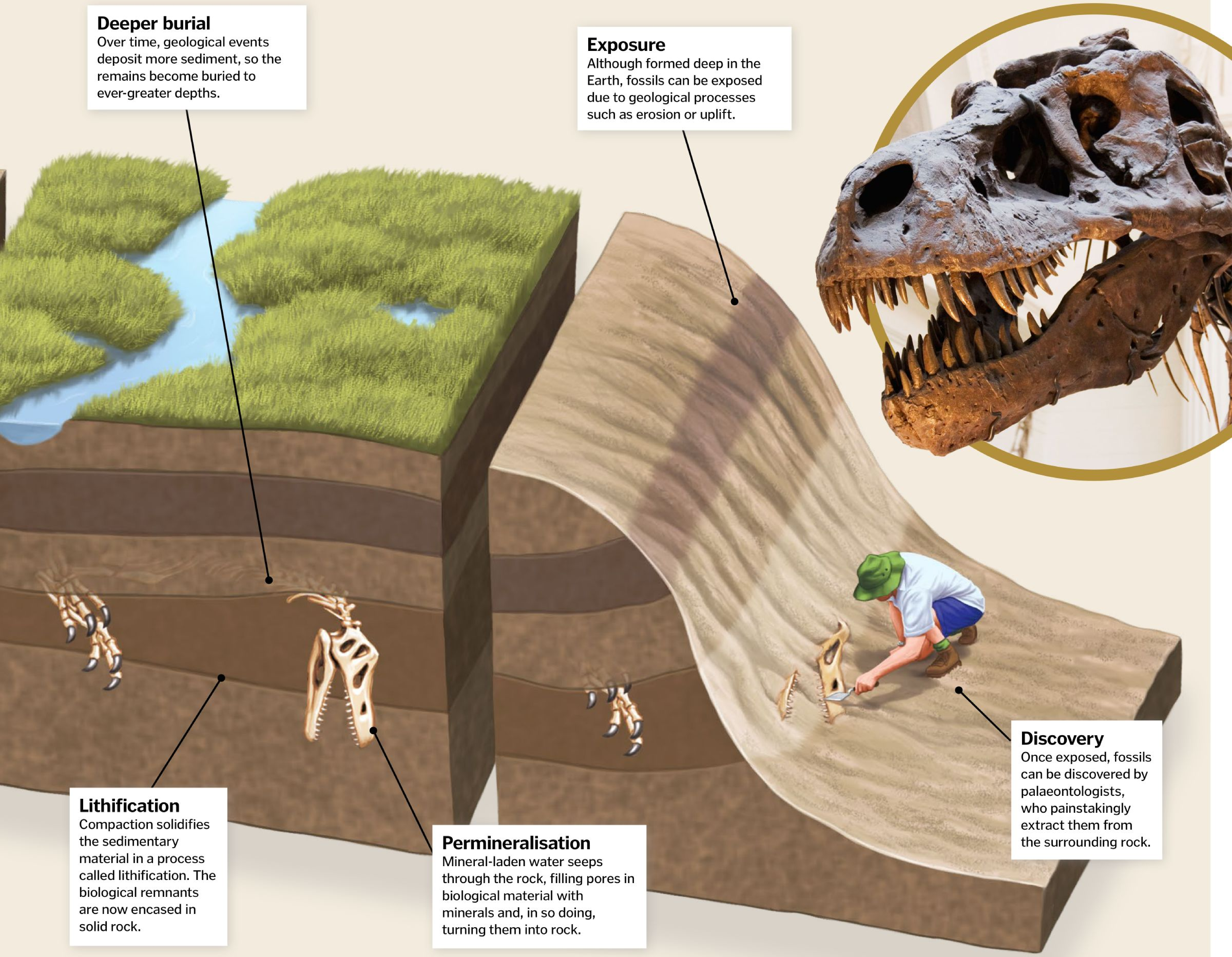
The rarest fossils

Soft tissue usually decays before fossilising, so fossils of creatures with no hard parts are rare. However, researchers at Berlin Free University recently found octopus fossils.

The family tree

Hominin fossils, such as the famous Lucy specimen, have enabled scientists to study human evolution. These findings have helped to shed light on our ancient cousins.





Deeper burial
Over time, geological events deposit more sediment, so the remains become buried to ever-greater depths.

Exposure
Although formed deep in the Earth, fossils can be exposed due to geological processes such as erosion or uplift.

Lithification
Compaction solidifies the sedimentary material in a process called lithification. The biological remnants are now encased in solid rock.

Permineralisation
Mineral-laden water seeps through the rock, filling pores in biological material with minerals and, in so doing, turning them into rock.

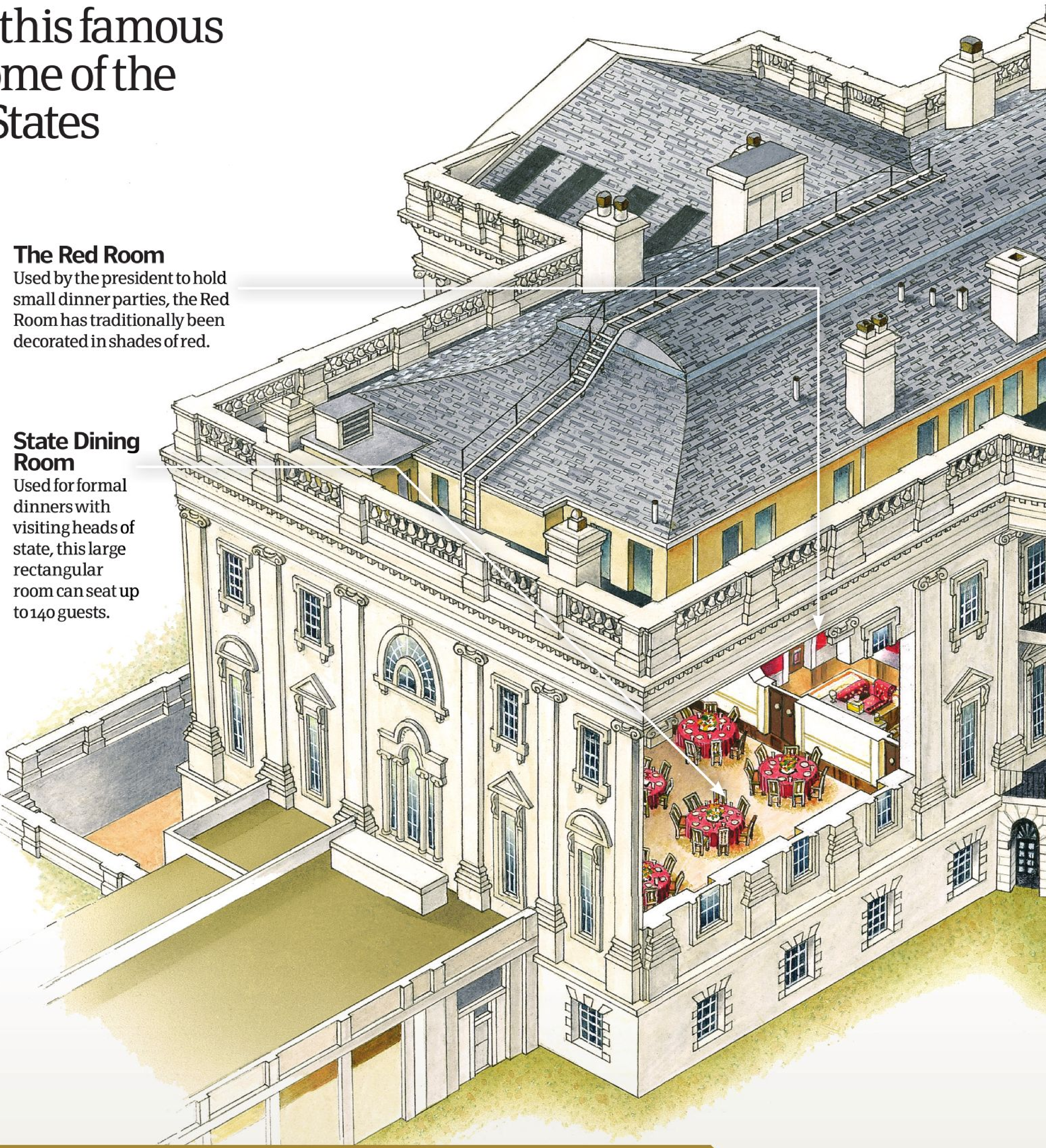
Discovery
Once exposed, fossils can be discovered by palaeontologists, who painstakingly extract them from the surrounding rock.

Inside the White House

For more than 200 years, this famous building has been the home of the presidents of the United States

A symbol of the presidency, the United States government and the American people, construction of the White House began in October 1792. Two years previously, President Washington, together with city planner Pierre L'Enfant, chose the site for the new presidential residence – the official address of which is now 1,600 Pennsylvania Avenue. As preparations began for the new federal city, an architectural competition was held to find a design for the 'President's House'. Nine proposals were submitted and Irish-born architect James Hoban won a gold medal for his practical and elegant design. Aside from the colonnades which link it to the East and West Wings, the White House has changed little in its appearance since its completion.

Although President Washington oversaw the construction of the house, he never lived in it. It was not until 1800, when the White House was nearly finished, that its first residents – President Adams and his wife – moved in. It survived a fire at the hands of the British in 1814 (during the War of 1812) and another fire in the West Wing in 1929, while President Hoover was in office. Throughout much of Harry Truman's presidency, the interior of the house was completely gutted and renovated, although the exterior stone walls, first put in place when the White House was constructed two centuries ago, were left in place. Since its completion in 1800, each president has made his own changes and additions to the house. Presidents can express their individual style in how they decorate some rooms and in how they receive the public during their stay.



The Red Room
Used by the president to hold small dinner parties, the Red Room has traditionally been decorated in shades of red.

State Dining Room
Used for formal dinners with visiting heads of state, this large rectangular room can seat up to 140 guests.

The West Wing

The West Wing houses the president's office (the Oval Office) and those of his senior staff. With room for about 50 employees, the wing also includes the Cabinet Room and the White House Situation Room. Built in 1901 due to overcrowding in the main house, the West Wing was damaged by fire in 1929, shortly after which a second storey was added. President William Howard Taft (1909-1913) engaged Nathan C Wyeth to extend the West Wing, which included the addition of the Oval Office. President Franklin Roosevelt (1933-1945) had the Oval Office moved to its present location, by the Rose Garden, during his tenure.

5 TOP FACTS The White House

The name

1 It has been known as the President's Palace, the President's House and the Executive Mansion. President Roosevelt officially christened it the White House in 1901.

The size

2 Looks can be deceptive – although the White House doesn't appear particularly large, it contains 132 rooms, 35 of which are bathrooms, spread over six floors.

The facilities

3 The White House has a variety of recreation facilities. These include a tennis court, jogging track, swimming pool, a bowling lane and private cinema among others.

The colour

4 As its name implies, the White House is white and requires regular re-painting to keep it looking fresh. Over 570 gallons of paint are needed to cover its exterior surface.

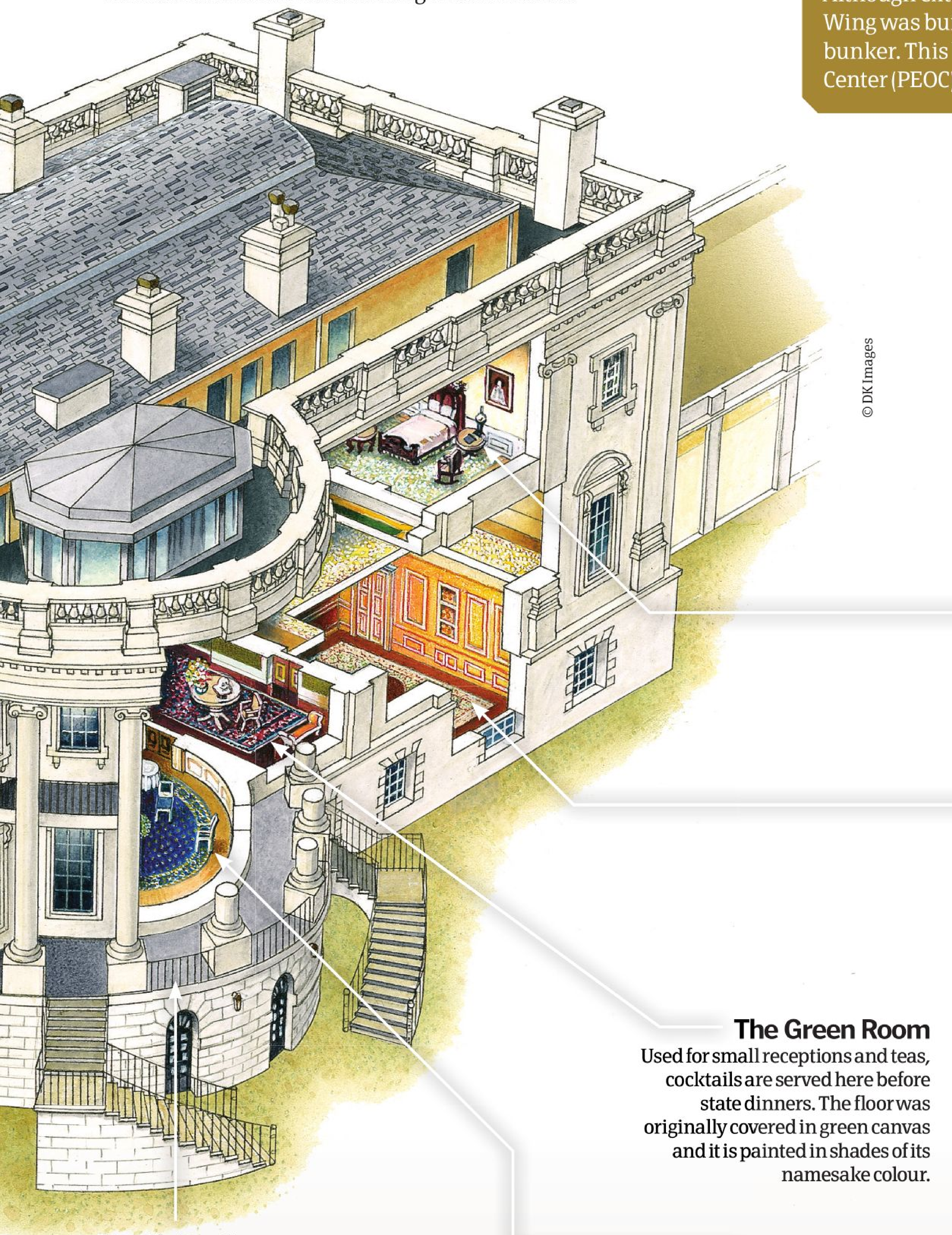
Instantly recognisable

5 Known throughout the world, the White House appears on the reverse of the $20 bill and has been blown up in countless films, such as *Independence Day*.

DID YOU KNOW? *The White House is the only private residence of a head of state that's open to the public free of charge*

Through the keyhole...

Although the White House was built between 1792 and 1800, the whole interior was gutted between 1948-1951 due to imminent structural failure. When reconstructed, a steel frame was inserted in place of the wooden one and most of the rooms were rebuilt in their former positions. However, some major features such as the Grand Staircase were relocated and essential innovations like air conditioning were installed.



© DK Images

The Lincoln Bedroom

Named after President Abraham Lincoln, this bedroom contains a bed purchased by Lincoln's wife and which has been slept in by a number of American presidents.

The Vermeil Room

Located on the ground floor, the Vermeil Room houses a collection of silver and portraits of American first ladies.

The Green Room

Used for small receptions and teas, cocktails are served here before state dinners. The floor was originally covered in green canvas and it is painted in shades of its namesake colour.

South Portico

This iconic portico was originally built to provide shade for the main rooms on sunny days and access to fresh air when it rained.

The Blue Room

Commonly mistaken for the Oval Office, the Blue Room is used for receptions, receiving lines and small dinners.

The East Wing

The East Wing, which contains additional office space, was added in 1942. Among its uses, the East Wing has intermittently housed the offices and staff of the president's wife (the first lady) and the White House Social Office. In 1977, Rosalynn Carter was the first to place her personal office in the East Wing and to formally call it the Office of the First Lady. Although extra office space at the White House had been needed for some time, the East Wing was built during WWII to hide the construction of an emergency underground bunker. This bunker has come to be known as the Presidential Emergency Operations Center (PEOC); it is said to have been designed to withstand 50 nuclear blasts.

The White House sits on an 18-acre plot of land, which includes a swimming pool and a tennis court

Below: the Oval Office; Bottom: interior shell of the White House during a renovation in 1950

The Latrobe White House

The architect Benjamin Latrobe made many additions to the original White House design, but most were destroyed in the fire of 1814

1 Entrance hall and state rooms

Most of Latrobe's drastic alterations to the interior of the White House were never actually undertaken.

2 Interior decoration

Latrobe designed furniture and decorations, which were introduced to the house, although all were decimated during the 1814 fire.

3 Water closets

Latrobe introduced toilets to the White House, missing from the original design.

4 Grand Staircase

Latrobe installed this staircase. It was rebuilt after the fire of 1814, but moved during President Truman's reconstruction of the interior.

5 West Colonnade

Built to house the White House laundry and storage.

6 East Colonnade

Built to house the White House stable block.

Executive Residence

The Executive Residence stands between the East and West Wings, linked by the East and West colonnades. It houses the president's private rooms (ie his home), as well as state rooms for ceremonies and official entertaining. The four main floors consist of the ground floor, which includes the Diplomatic Reception Room, Vermeil Room, the main kitchen and other offices; the State Floor, which contains the Green Room, Blue Room, Red Room, State Dining Room and Grand Staircase; the second floor is the family residence including bedrooms etc; while the third floor contains a solarium and a games room.

The Iguanodon

Unearth one of the very first dinosaurs to be discovered by humankind

It's very easy to find ourselves captivated by big, fearsome carnivores. We imagine them prowling the plains and forests of the Mesozoic Era, stalking and hunting the peaceful herbivores and roaring with vindication as they overcome their prey and claim a meal. But we often neglect to pay attention to their prey, to the herbivores that have merited an equal place in natural history. Some – such as the Iguanodons – also have a key place in our own history, marking a milestone in our fledgling efforts to study dinosaurs.

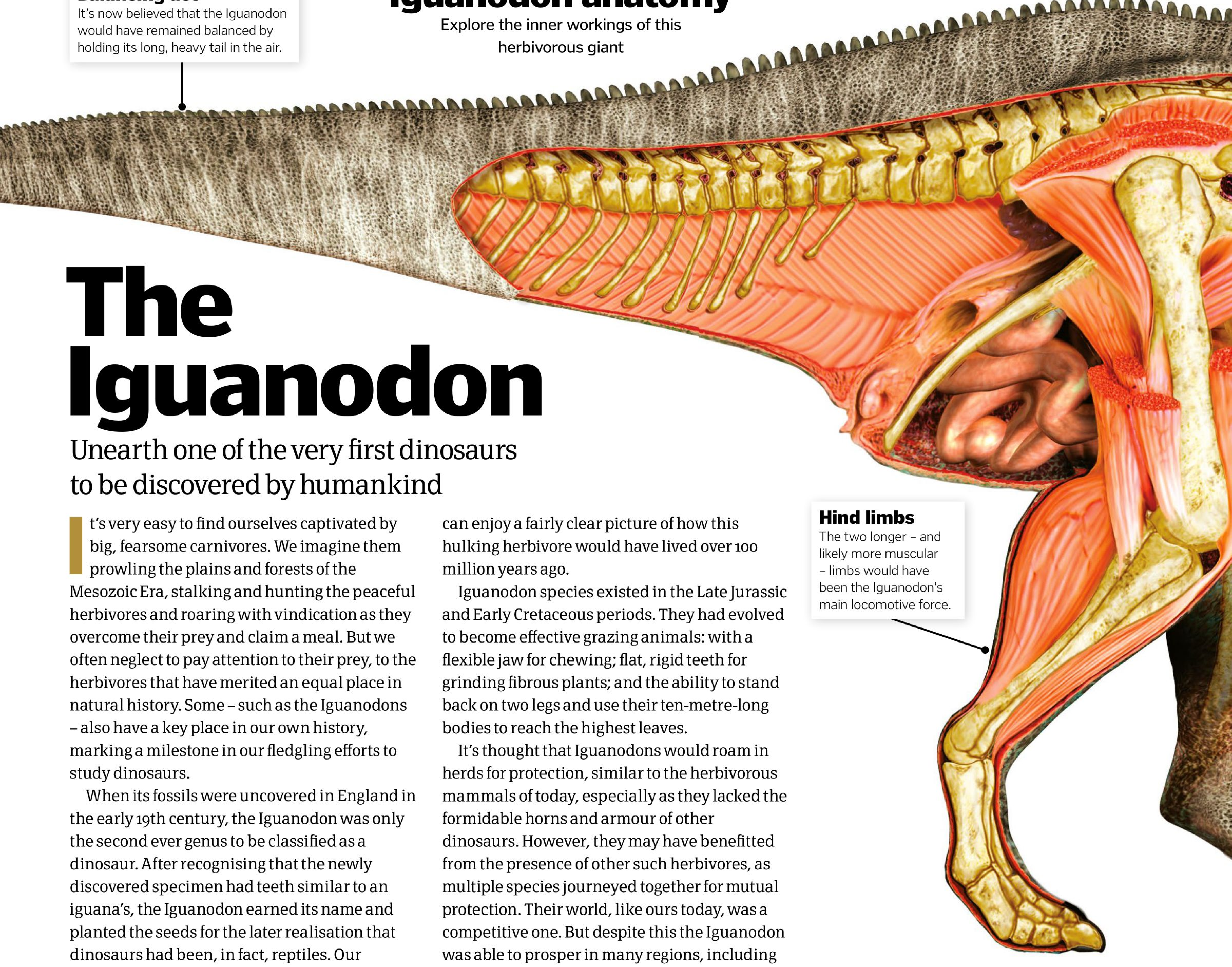
When its fossils were uncovered in England in the early 19th century, the Iguanodon was only the second ever genus to be classified as a dinosaur. After recognising that the newly discovered specimen had teeth similar to an iguana's, the Iguanodon earned its name and planted the seeds for the later realisation that dinosaurs had been, in fact, reptiles. Our perception of the Iguanodon has vastly changed and developed through the years, and today we can enjoy a fairly clear picture of how this hulking herbivore would have lived over 100 million years ago.

Iguanodon species existed in the Late Jurassic and Early Cretaceous periods. They had evolved to become effective grazing animals: with a flexible jaw for chewing; flat, rigid teeth for grinding fibrous plants; and the ability to stand back on two legs and use their ten-metre-long bodies to reach the highest leaves.

It's thought that Iguanodons would roam in herds for protection, similar to the herbivorous mammals of today, especially as they lacked the formidable horns and armour of other dinosaurs. However, they may have benefitted from the presence of other such herbivores, as multiple species journeyed together for mutual protection. Their world, like ours today, was a competitive one. But despite this the Iguanodon was able to prosper in many regions, including modern-day North Africa, Europe, Asia, Australia and North America.

Iguanodon anatomy

Explore the inner workings of this herbivorous giant



Balancing act
It's now believed that the Iguanodon would have remained balanced by holding its long, heavy tail in the air.

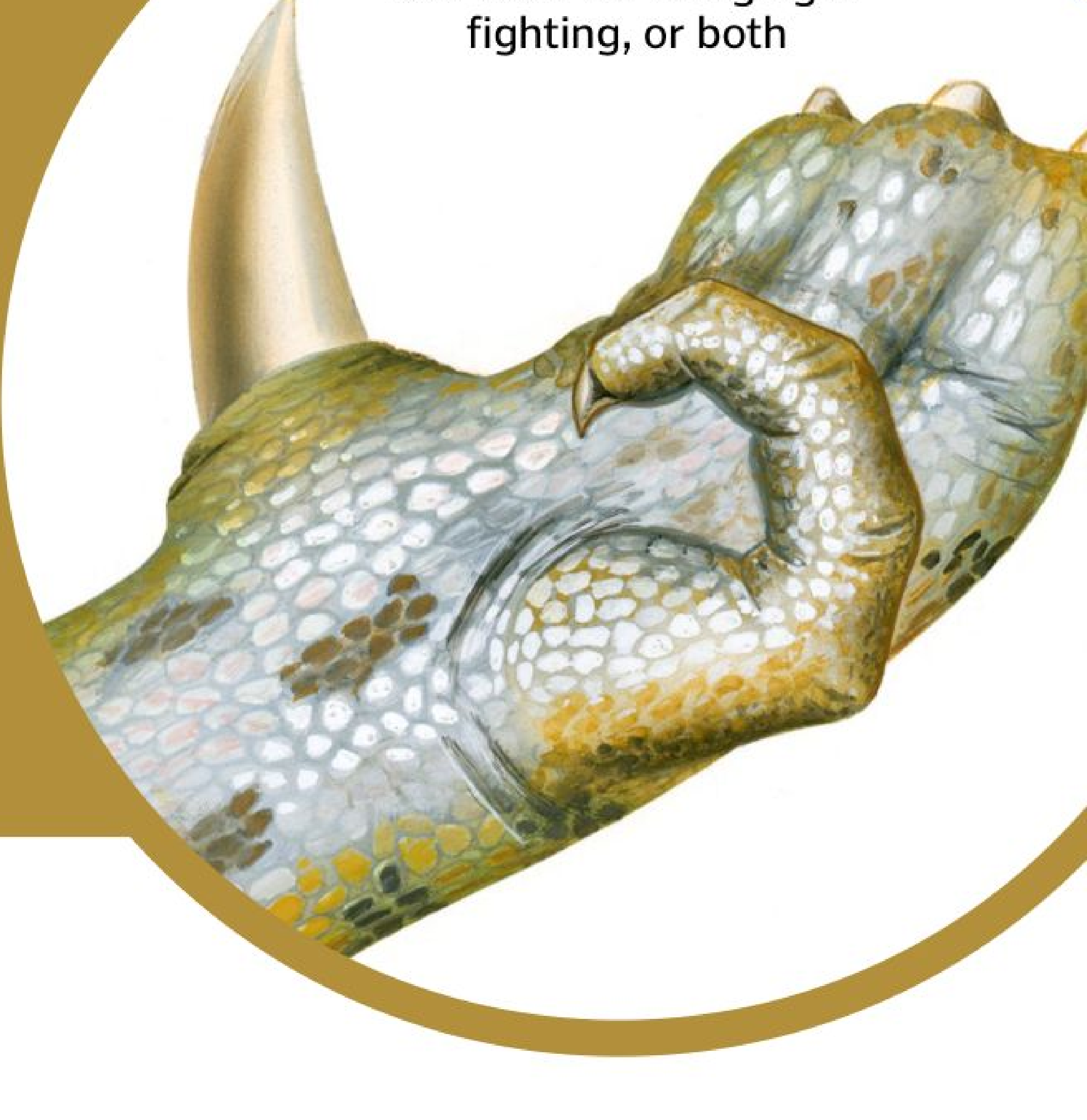
Hind limbs
The two longer – and likely more muscular – limbs would have been the Iguanodon's main locomotive force.

Thumbs-up for Iguanodons

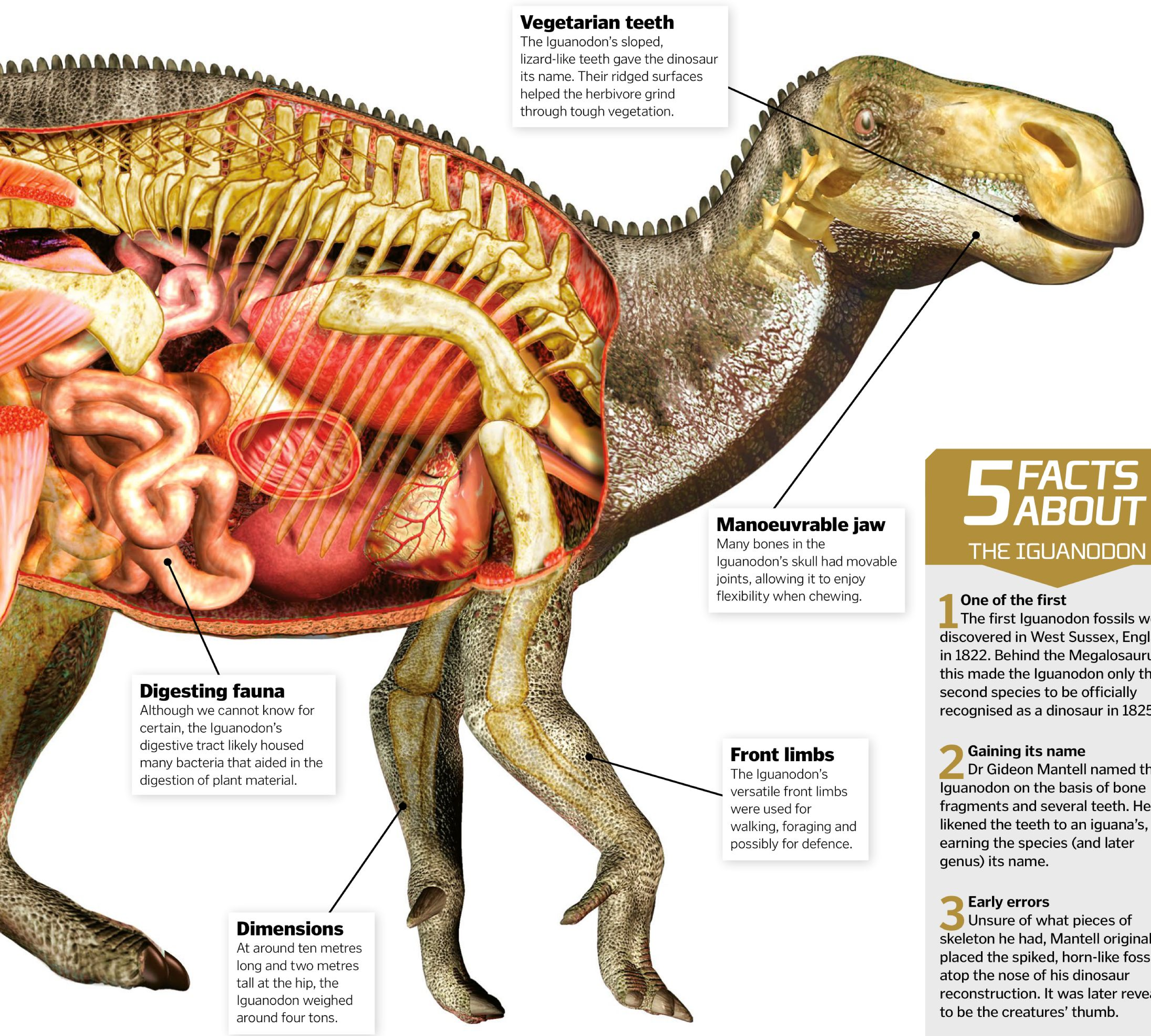
The Iguanodon's hand anatomy has captivated palaeontologists since its discovery. The species possessed a five-digit hand composed of three thick, blunt fingers, one unbound fourth finger that protruded laterally from its palm, and an intriguing thumb-spike. We understand that the spike originated via fused thumb joints, but its function remains a mystery.

Some have postulated that the spike's primary use was for defence, either from potential predators or from rival Iguanodons. They argue that the dinosaur would have used the sharp thumbs to stab at opponents when engaged in close combat. Some go further and suggest that the spike may have housed a venom gland, adding an extra layer of lethality to the hand-wielded weapon.

Others believe the curious feature had a more peaceful purpose. It may have simply been used for breaking into nuts and seeds, or potentially for stripping foliage from trees before consumption.



It is still unknown whether the Iguanodon's thumb-spike was used for foraging or fighting, or both



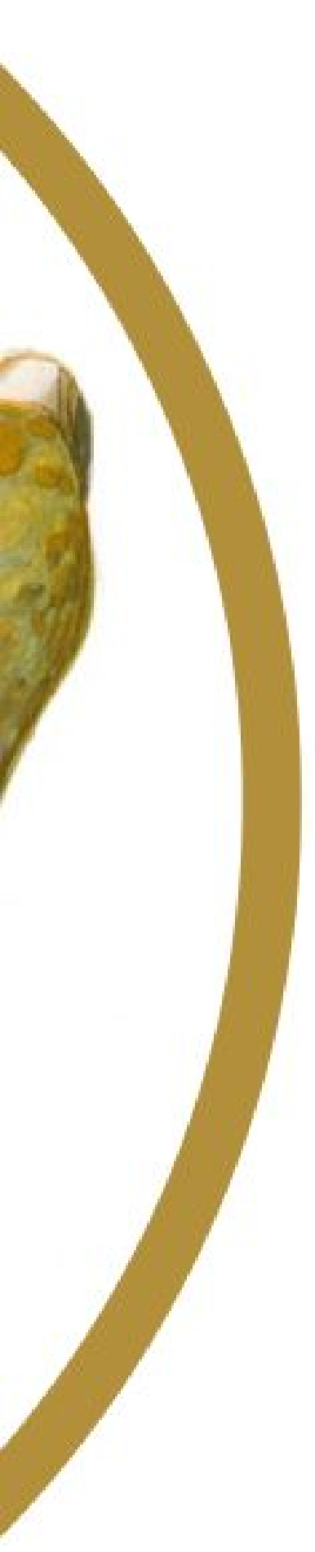
Vegetarian teeth
The Iguanodon's sloped, lizard-like teeth gave the dinosaur its name. Their ridged surfaces helped the herbivore grind through tough vegetation.

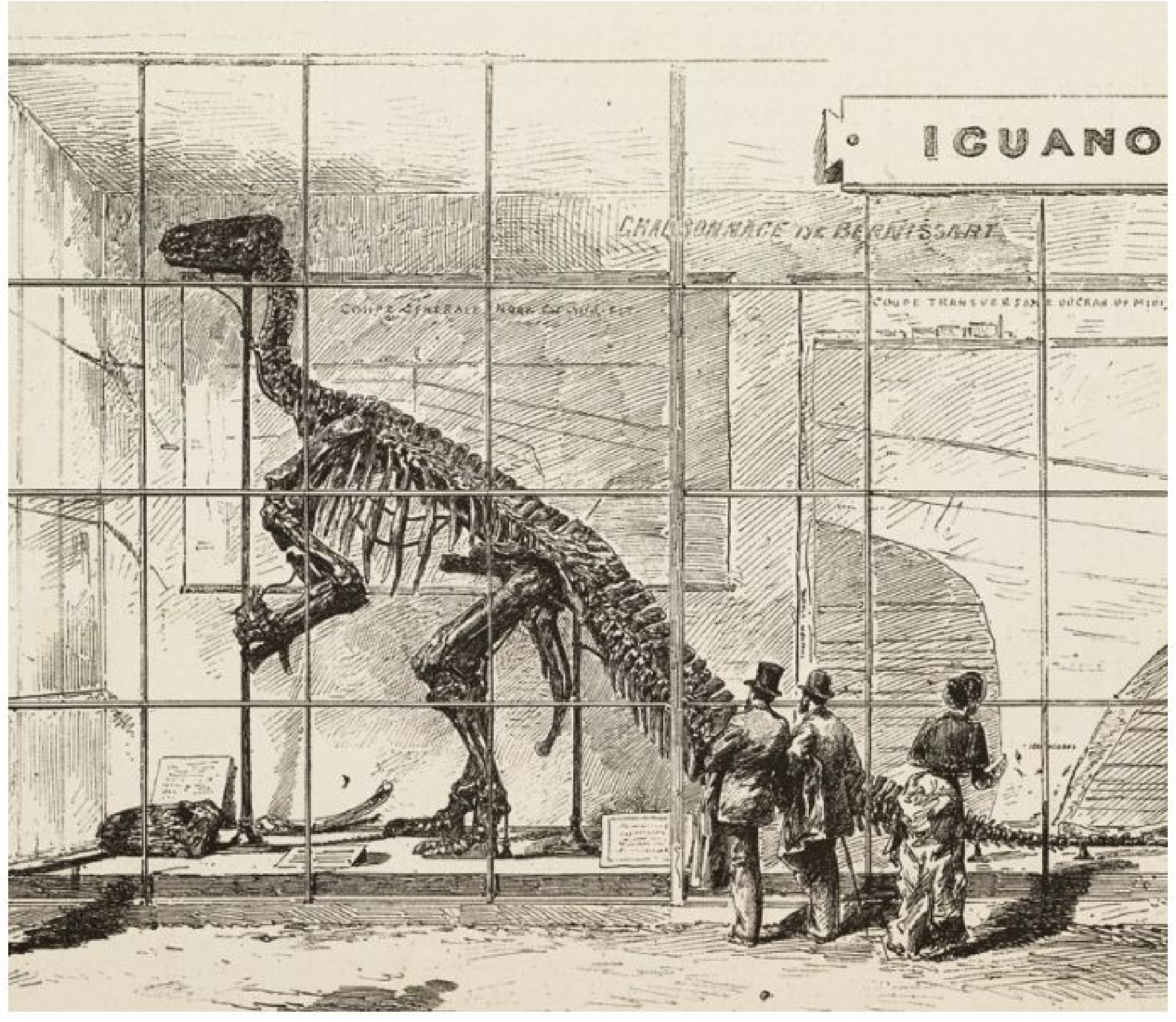
Manoeuvrable jaw
Many bones in the Iguanodon's skull had movable joints, allowing it to enjoy flexibility when chewing.

Digesting fauna
Although we cannot know for certain, the Iguanodon's digestive tract likely housed many bacteria that aided in the digestion of plant material.

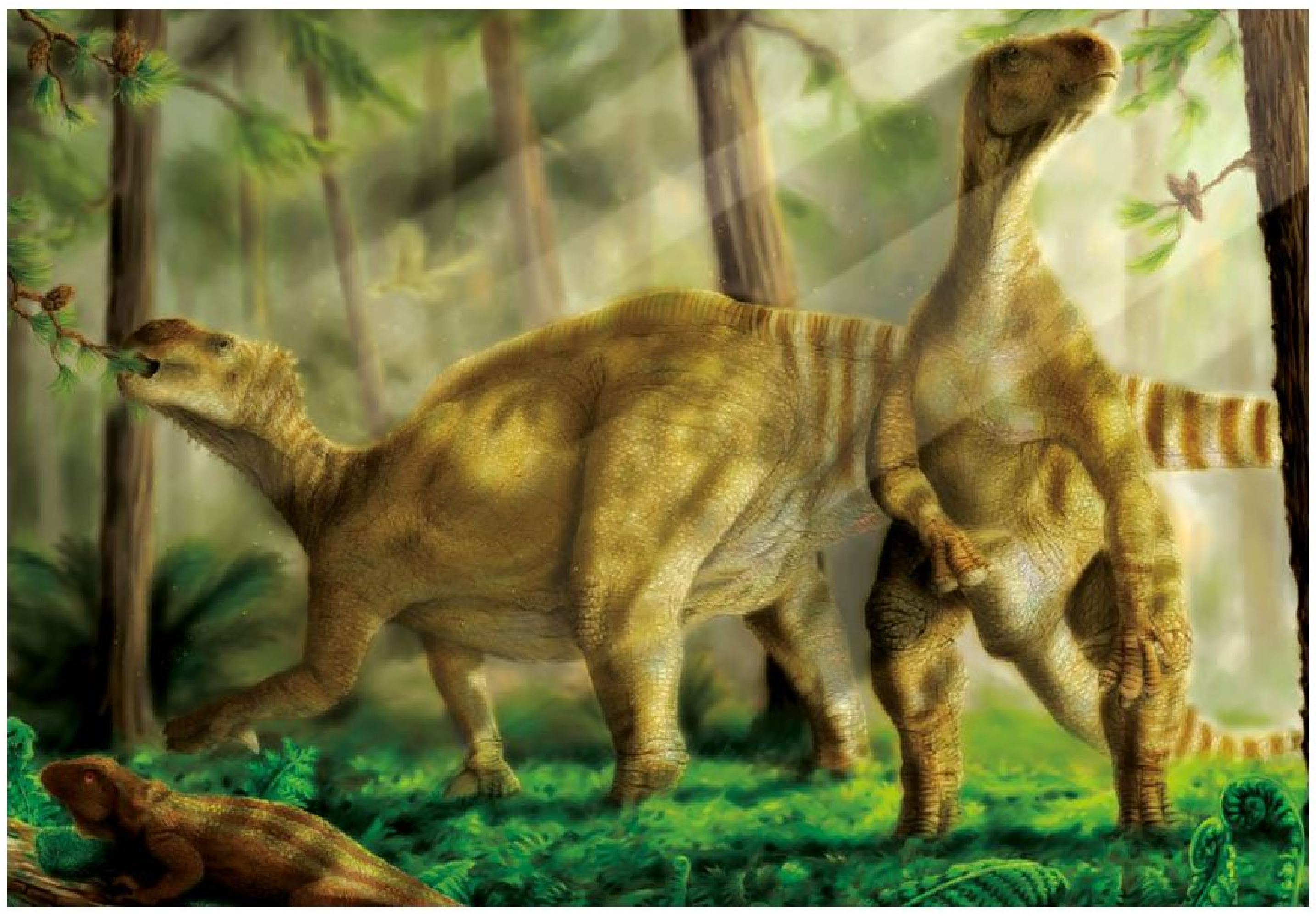
Front limbs
The Iguanodon's versatile front limbs were used for walking, foraging and possibly for defence.

Dimensions
At around ten metres long and two metres tall at the hip, the Iguanodon weighed around four tons.





For years scientists believed that the Iguanodon moved in an upright posture similar to a kangaroo



Like many herbivorous dinosaurs, the Iguanodon was a giant. Its height was a useful asset for reaching food

5 FACTS ABOUT THE IGUANODON

1 One of the first
The first Iguanodon fossils were discovered in West Sussex, England, in 1822. Behind the Megalosaurus, this made the Iguanodon only the second species to be officially recognised as a dinosaur in 1825.

2 Gaining its name
Dr Gideon Mantell named the Iguanodon on the basis of bone fragments and several teeth. He likened the teeth to an iguana's, earning the species (and later genus) its name.

3 Early errors
Unsure of what pieces of skeleton he had, Mantell originally placed the spiked, horn-like fossil atop the nose of his dinosaur reconstruction. It was later revealed to be the creatures' thumb.

4 A large find
In the 1870s, miners in Belgium found a collection of 30 relatively complete Iguanodon skeletons. This finding helped to vastly improve our understanding of their anatomy and suggested that the dinosaurs may have lived in herds.

5 Kangaroo to something new
For many years the scientific community believed the Iguanodon was a pure biped, bearing a similar stance to today's kangaroo. However, we now believe Iguanodons were horizontally aligned and only semi-bipedal.

© Getty

Hampton Court Palace

From Henry VIII's love nest to Queen Victoria's restoration project: inside the 500-year-old royal residence

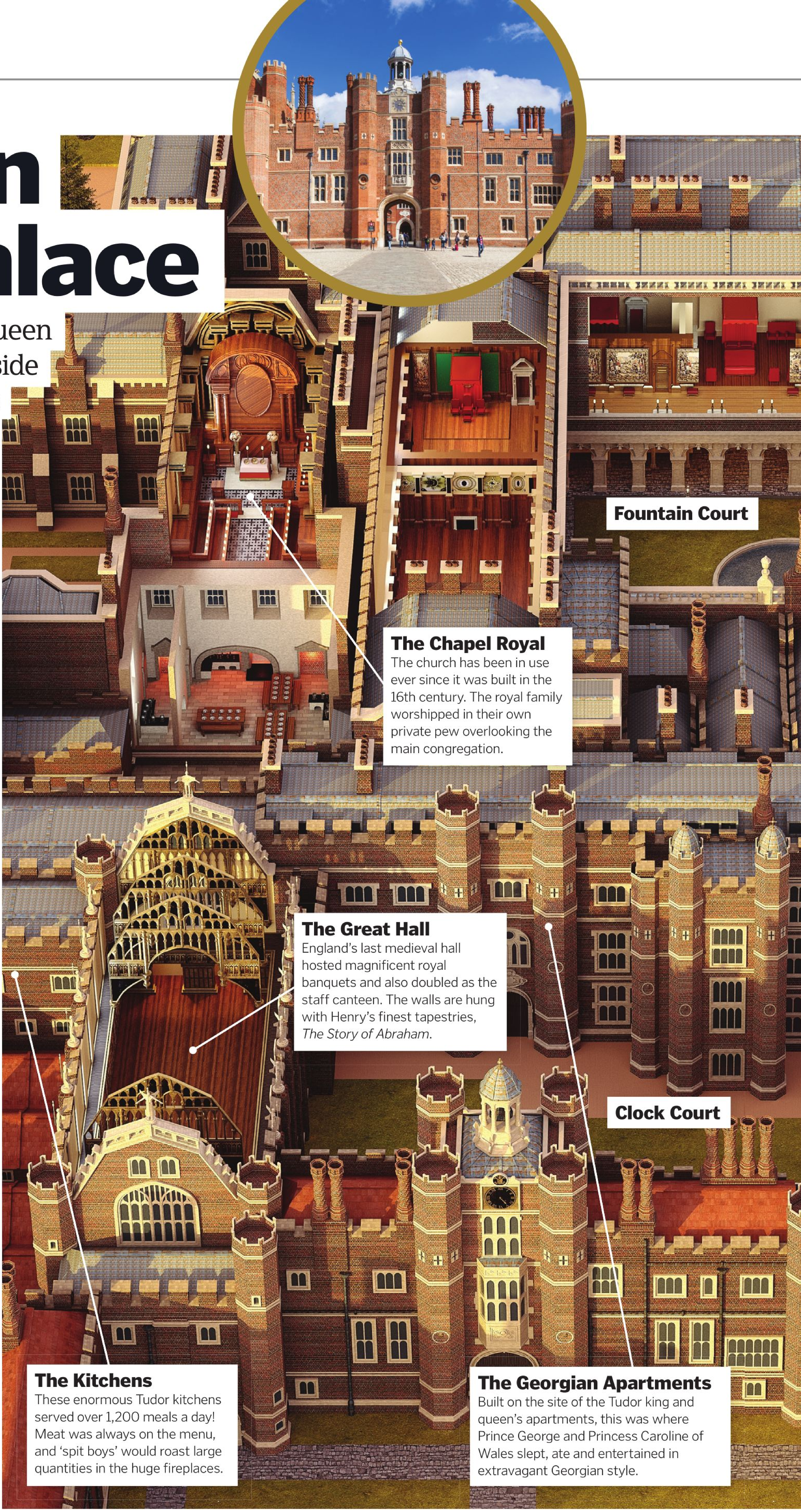
One of England's most treasured historic palaces, Hampton Court was famously home to King Henry VIII, along with his many wives, lovers and scandals. However, the property was originally owned by the monarch's trusted advisor Cardinal Thomas Wolsey, before he was accused of treason and fell from favour, losing his status and stately home.

In 1529, the king and his future queen Anne Boleyn set about making a few royal redesigns. The lovers' initials were carved into the woodwork, and the new queen's lodgings were planned. However, Anne would never use these apartments, as she too fell from the king's grace. After her execution in 1536 Henry ordered that all trace of her be removed, but you can still see an interlocking 'H' and 'A' lying in a forgotten corner of the palace's Great Hall, which the pair had commissioned together.

Beyond this magnificent dining hall lay the king's private chambers, but these were later demolished by King William III and Queen Mary II between 1689–94. By this time the Tudor Gothic style was old-fashioned, so the royal couple commissioned architect Sir Christopher Wren to remodel the palace.

A sweeping staircase leads to William III's State Apartments – a series of grand rooms where he would address high-ranking courtiers. However, the king was happiest in his private apartments, including his personal study and bedroom, all lined with paintings from his collection. William and Mary also built an elaborate maze and Privy garden in Hampton Court's grounds, and they even had chocolate kitchens installed – a relatively new delicacy in England and a luxury only few could afford.

By the Georgian period Hampton Court was in decline. No British monarch lived there again after 1737, and its many apartments were awarded to courtiers – that is, until Queen Victoria ordered the gates to be 'thrown open to all her subjects' in 1838. The palace was so popular that restoration work was gradually carried out to preserve its history, and visitors still come from all over the world to follow in the footsteps of royalty.



The Chapel Royal
The church has been in use ever since it was built in the 16th century. The royal family worshipped in their own private pew overlooking the main congregation.

The Great Hall
England's last medieval hall hosted magnificent royal banquets and also doubled as the staff canteen. The walls are hung with Henry's finest tapestries, *The Story of Abraham*.

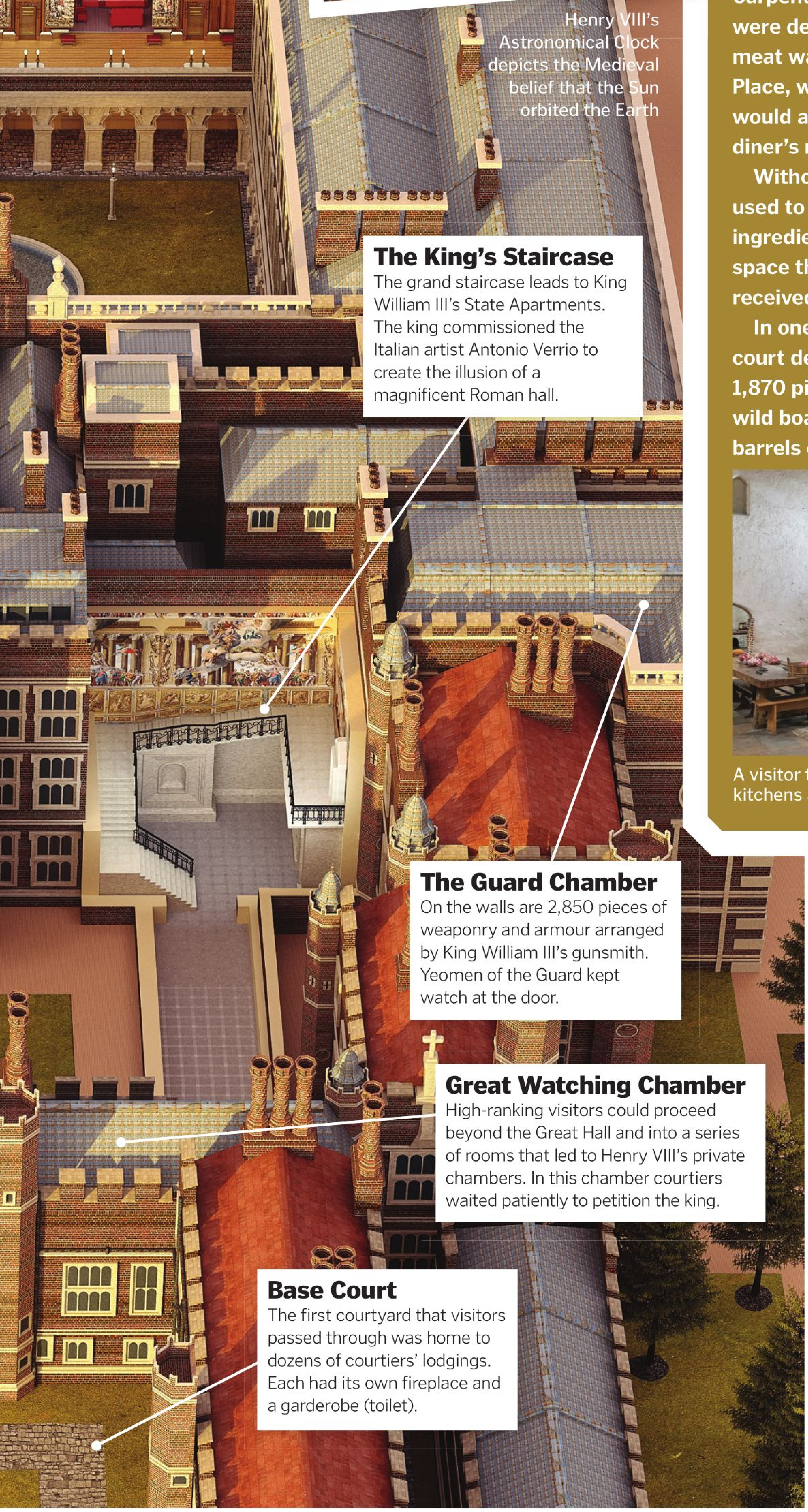
The Kitchens
These enormous Tudor kitchens served over 1,200 meals a day! Meat was always on the menu, and 'spit boys' would roast large quantities in the huge fireplaces.

The Georgian Apartments
Built on the site of the Tudor king and queen's apartments, this was where Prince George and Princess Caroline of Wales slept, ate and entertained in extravagant Georgian style.

© Getty; Alamy; Illustration by Nicholas Forder

DID YOU KNOW? *The first buildings at Hampton Court were built for the Knights Hospitallers of St John sometime before 1338*

Henry VIII's Astronomical Clock depicts the Medieval belief that the Sun orbited the Earth



The King's Staircase

The grand staircase leads to King William III's State Apartments. The king commissioned the Italian artist Antonio Verrio to create the illusion of a magnificent Roman hall.

The Guard Chamber

On the walls are 2,850 pieces of weaponry and armour arranged by King William III's gunsmith. Yeomen of the Guard kept watch at the door.

Great Watching Chamber

High-ranking visitors could proceed beyond the Great Hall and into a series of rooms that led to Henry VIII's private chambers. In this chamber courtiers waited patiently to petition the king.

Base Court

The first courtyard that visitors passed through was home to dozens of courtiers' lodgings. Each had its own fireplace and a garderobe (toilet).

Tudor dining

At Hampton Court you can feast your eyes on the largest surviving Renaissance kitchens in Europe. To cater for hundreds of people twice daily was an immense task, so Henry VIII's enormous food factory was organised into various departments. These included the Master Carpenter's Court, where the supplies were delivered, the Boiling House, where meat was prepared, and the Serving Place, where the clerk of the kitchens would allocate dishes according to the diner's rank.

Without fridges, the Fish Court was used to temporarily store raw ingredients. This was a narrow, outdoor space that ran north to south, so it received little sunlight.

In one year of Elizabeth I's reign the court devoured 8,200 sheep, 2,330 deer, 1,870 pigs, 1,240 oxen, 760 calves and 53 wild boar! This was all washed down with barrels of wine, beer and ale.

A visitor to the Tudor court in 1554 described the kitchens as 'veritable hells'

5 FACTS ABOUT LIFE AT THE PALACE

1 Palace or prison? After Charles I's (1625–49) defeat in the Civil War, the palace became his prison. He was placed under house arrest in 1649 but escaped through the Privy Garden. He was recaptured and executed.

2 Historic hauntings The Victorians loved ghost stories and claimed the palace was haunted by the spirits of two of Henry's wives: Jane Seymour and Catherine Howard.

3 Royal entertainment The Stuarts used Henry VIII's Great Hall as the setting for court masques – spectacles of dance, music and drama. William Shakespeare's company, the King's Men, performed for King James I.

4 Luxurious lavatories When nature called, Henry VIII used a 'close stool' – a padded velvet stool with a hole in the centre and a chamber pot underneath. Lower members of court used a 14-seater lavatory over the moat.

5 A romantic gesture Charles II commissioned a mile-long canal for his bride, Catherine of Braganza. Swan-shaped boats sailed along it during their honeymoon.

> *"Queen Victoria ordered the gates to be 'thrown open to all her subjects'"*

This maze was commissioned around 1700 by William III. It's the UK's oldest surviving hedge maze

Tiger tank anatomy

Nazi Germany's ultimate heavy panzer was designed to strike a decisive blow for the Third Reich

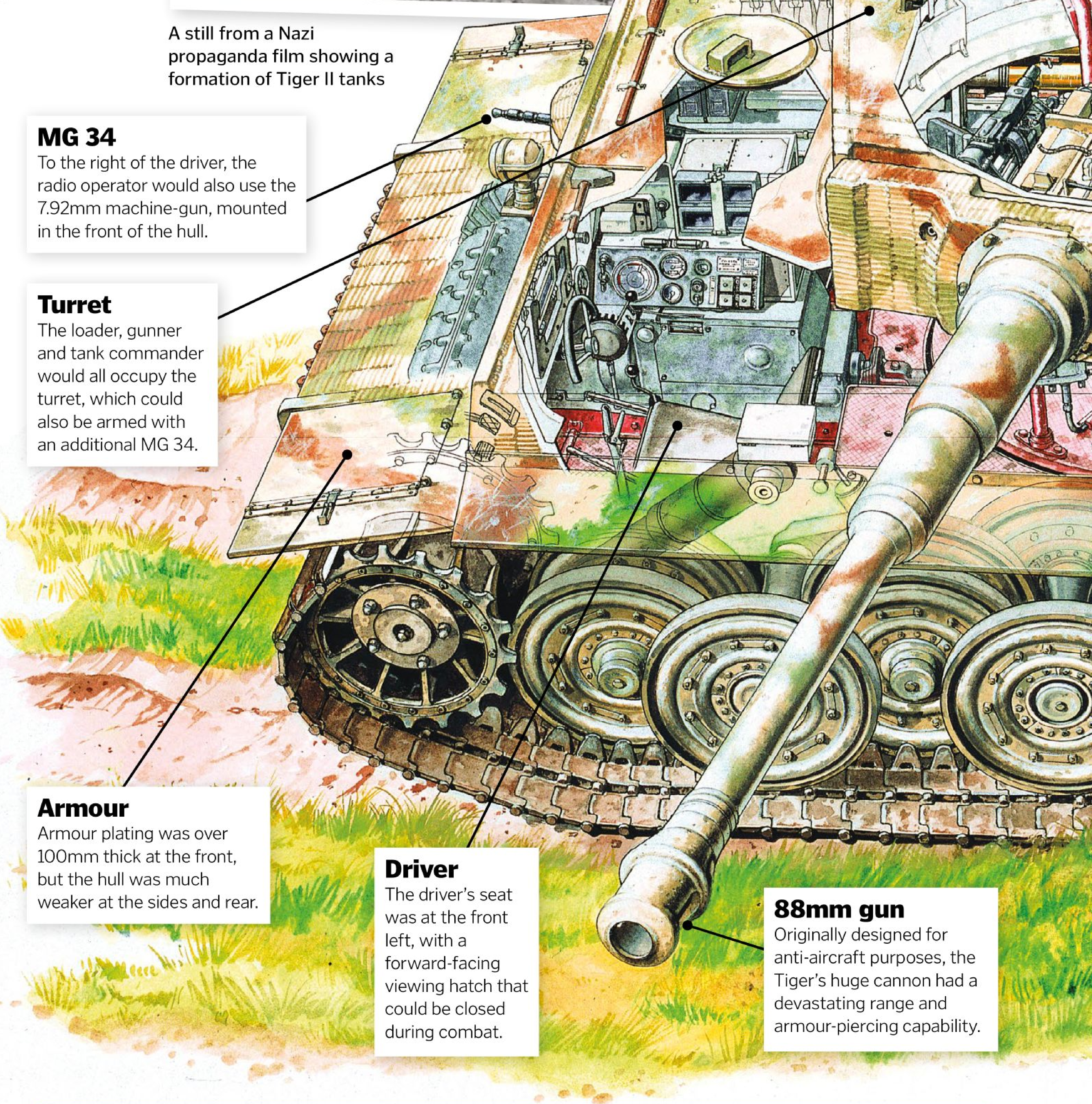
The Panzerkampfwagen VI, more commonly known as the Tiger I, was developed in the early 1940s with the aim of creating an unstoppable armoured killing machine for the German military. Two rival engineering companies, Porsche and Henschel, were approached to produce prototypes for the tank, meeting specifications such as weight, cost and weapon capability. Henschel's design was eventually selected and rushed onto the production line in order to quickly deploy on the Eastern Front, joining Hitler's ongoing invasion of the Soviet Union.

It took five crewmembers to operate the Tiger: a driver, gunner, loader, commander and radio operator. The tank's main weapon was a 88mm gun, which was originally designed as an anti-aircraft artillery piece. At the time of the Tiger's first deployment, this huge cannon was capable of penetrating any enemy armour from long range. Years after its first deployment, during the Battle of Normandy in 1944, this enabled Tiger crews to ambush Allied formations from a distance, unleashing devastating fire before their enemy had a chance to respond.

The Tiger's armour was 100mm thick at the front – strong enough to stop or deflect nearly any Allied return fire. Battlefield accounts of Tigers in combat report round after round of enemy fire failing to penetrate this formidable shell. Unlike another prolific German tank, the Panther V, the steel plate protection of early Tigers was not angled, which provided less protection. This angled design feature was later added to the King Tiger, which was completed in the final months of the war – too late to prevent the defeat of Nazi Germany.

Despite its fearsome reputation on the battlefield, the Allies were eventually able to counter the Tiger I's capabilities – outnumbering, outmanoeuvring and eventually outgunning the once-dominant machine. Today, the Tiger remains among the most iconic vehicles of WWII and a milestone in the history of armoured warfare.

A still from a Nazi propaganda film showing a formation of Tiger II tanks



MG 34
To the right of the driver, the radio operator would also use the 7.92mm machine-gun, mounted in the front of the hull.

Turret
The loader, gunner and tank commander would all occupy the turret, which could also be armed with an additional MG 34.

Armour
Armour plating was over 100mm thick at the front, but the hull was much weaker at the sides and rear.

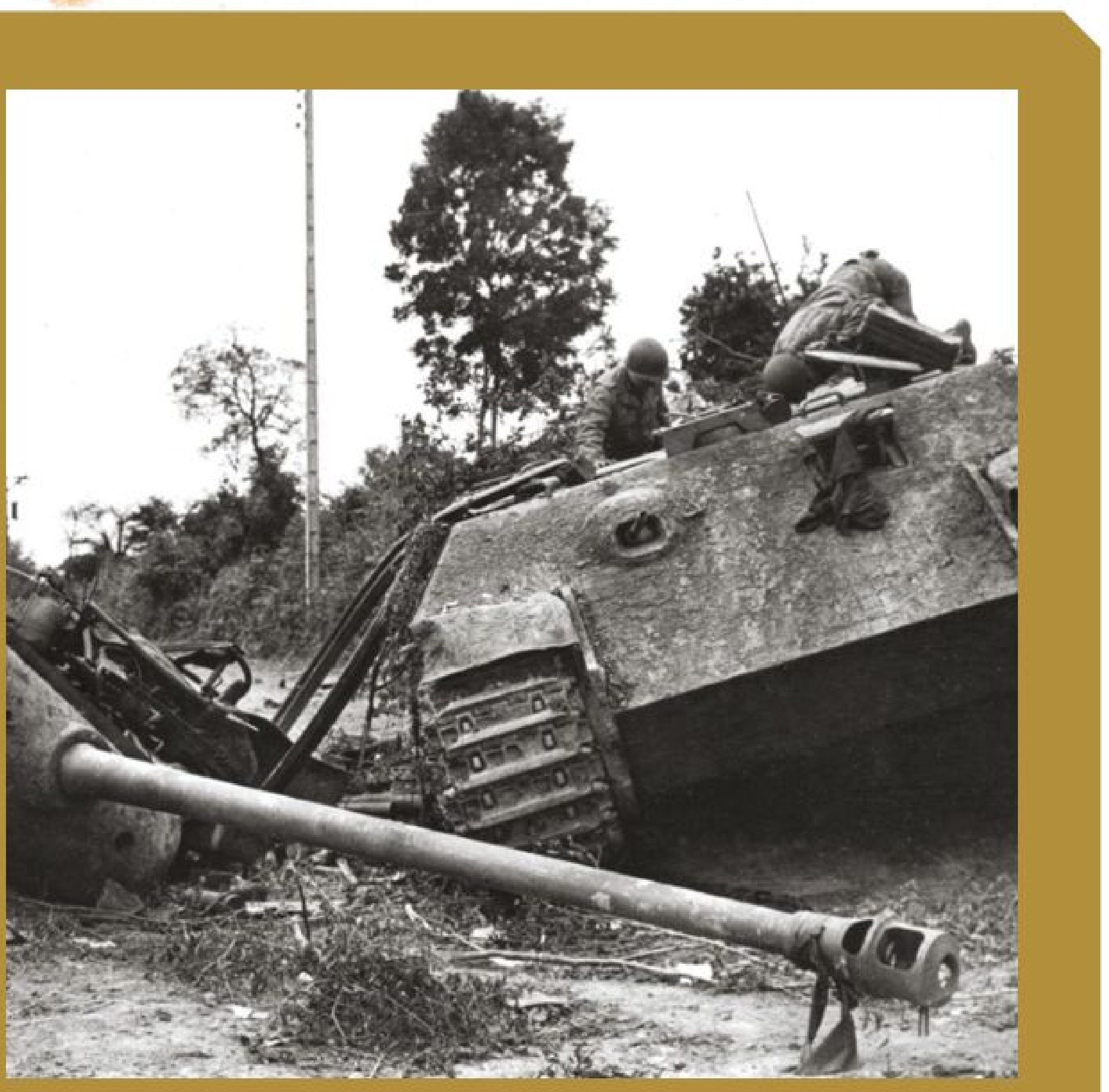
Driver
The driver's seat was at the front left, with a forward-facing viewing hatch that could be closed during combat.

88mm gun
Originally designed for anti-aircraft purposes, the Tiger's huge cannon had a devastating range and armour-piercing capability.

A paper Tiger?

Although the armour and weaponry of the Tiger posed a formidable threat on the battlefield, the tank never struck the decisive blow so desperately desired by the German high command. Among the main challenges to the Tiger was the number that could be deployed. Germany's military factories became targets for Allied bombers, and key components for the tank's production became delayed, meaning fewer were ready to join the frontline than expected.

In addition, the tank's size and complexity, including the innovative suspension system, made it much more expensive and time-consuming to produce. High fuel consumption was also a major drawback to the tank's effectiveness, meaning it only had an off-road range of up to 110 kilometres.

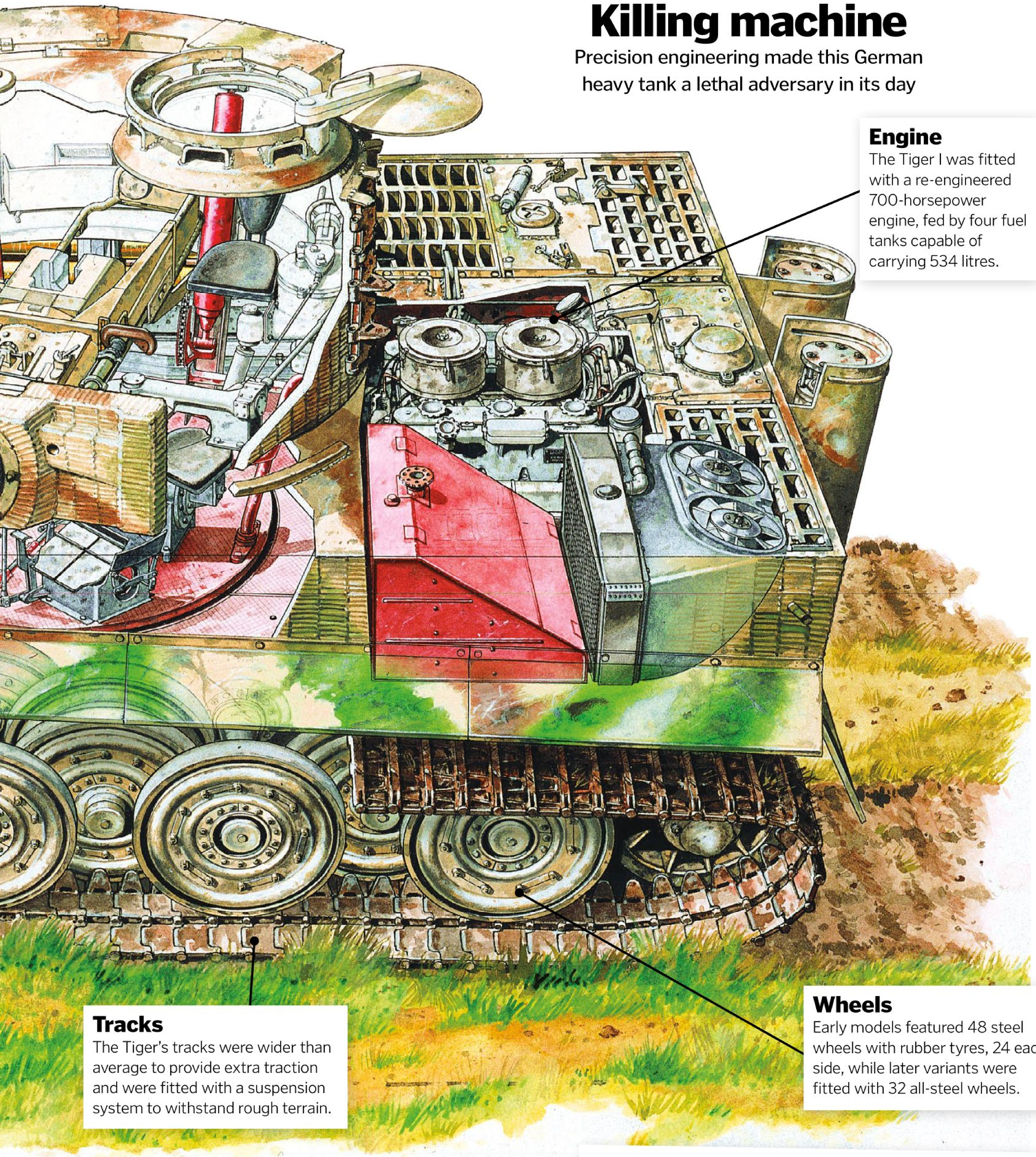


A destroyed Tiger II 'King Tiger': production costs also hamstrung the Tiger's successor

DID YOU KNOW? *Only around 1,300 Tiger Is were built during WWII, compared with over 50,000 T-34 Soviet tanks*

Killing machine

Precision engineering made this German heavy tank a lethal adversary in its day



Engine
The Tiger I was fitted with a re-engineered 700-horsepower engine, fed by four fuel tanks capable of carrying 534 litres.

Tracks
The Tiger's tracks were wider than average to provide extra traction and were fitted with a suspension system to withstand rough terrain.

Wheels
Early models featured 48 steel wheels with rubber tyres, 24 each side, while later variants were fitted with 32 all-steel wheels.

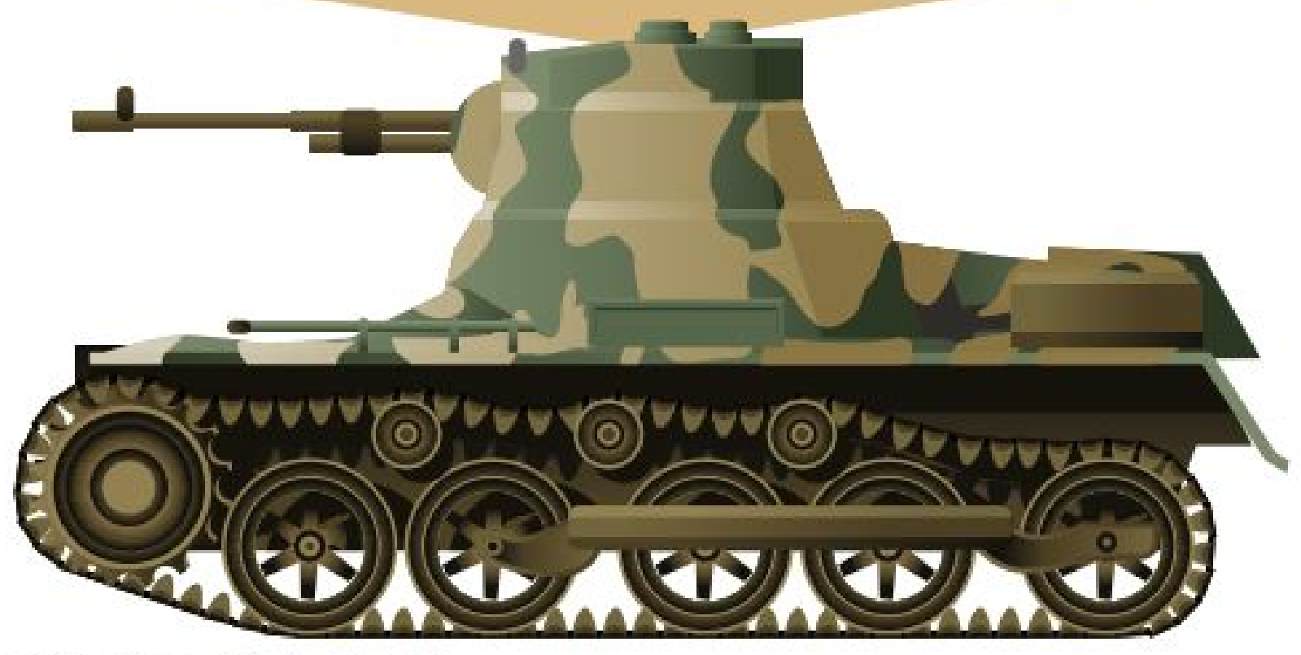
Other big cats

Although the Tiger I was the most numerous and notorious of Nazi Germany's heavy tanks, several other versions were also developed to tackle specific combat scenarios. The Panzerjäger Tiger, or 'Elefant', was a tank destroyer based on the chassis of a Tiger but designed to hunt down enemy vehicles. The Elefant featured a fixed turret, meaning that it could not rotate to adjust its aim, and its 88mm gun therefore stretched out across the front of the chassis, resembling an elephant's trunk.

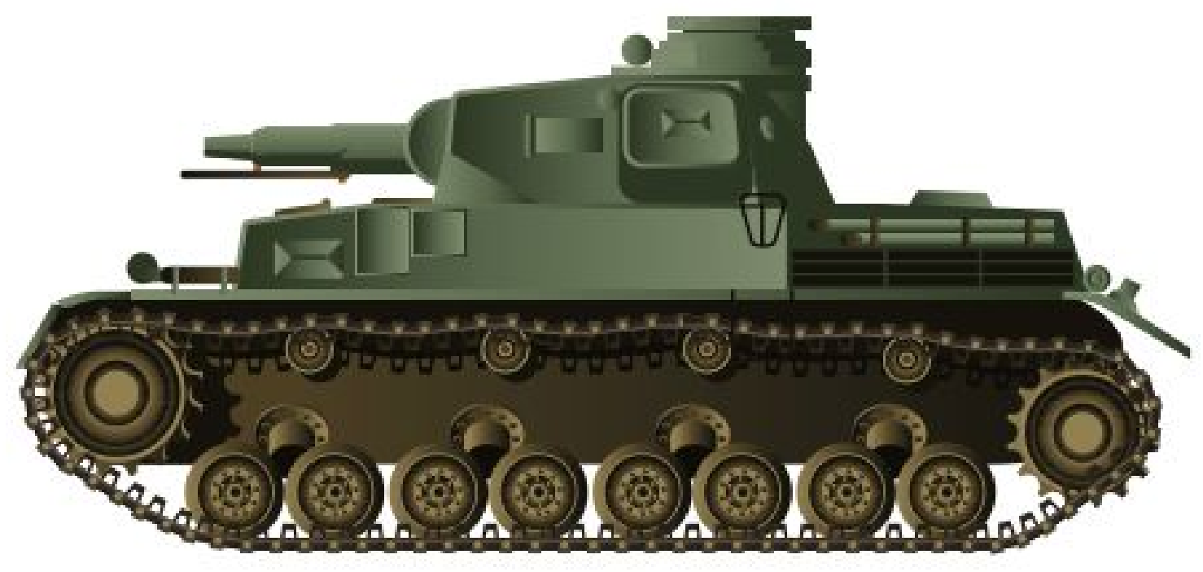
Another short-lived Tiger variant was the Sturmtiger, an assault gun that was developed with one job in mind – to demolish anything and everything that stood in its way. Armed with a massive 380mm cannon, the Sturmtiger fired rocket-propelled shells that could lay waste to massed enemy positions, or even obliterate buildings. Only 19 Sturmtigers were ever developed, making them another curious but small footnote in the history of the Tiger tank.

The Elefant featured a fixed 88mm gun on a Tiger chassis and was deployed as a tank destroyer

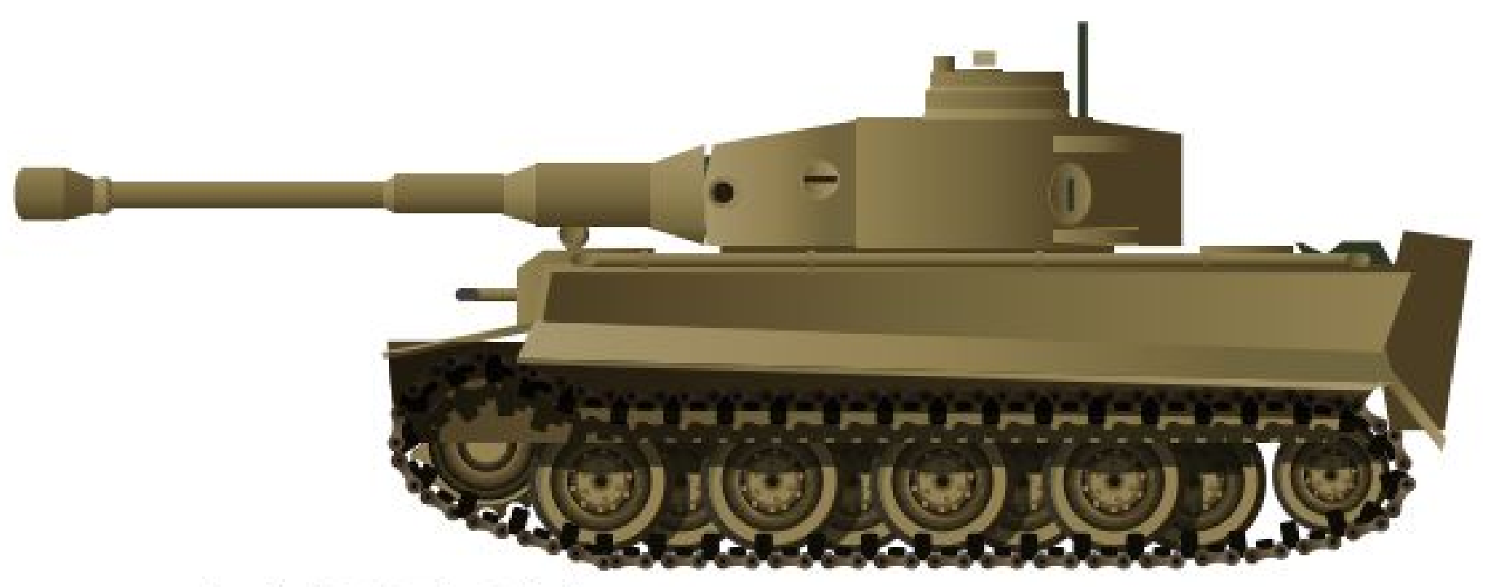
Evolution of German armour



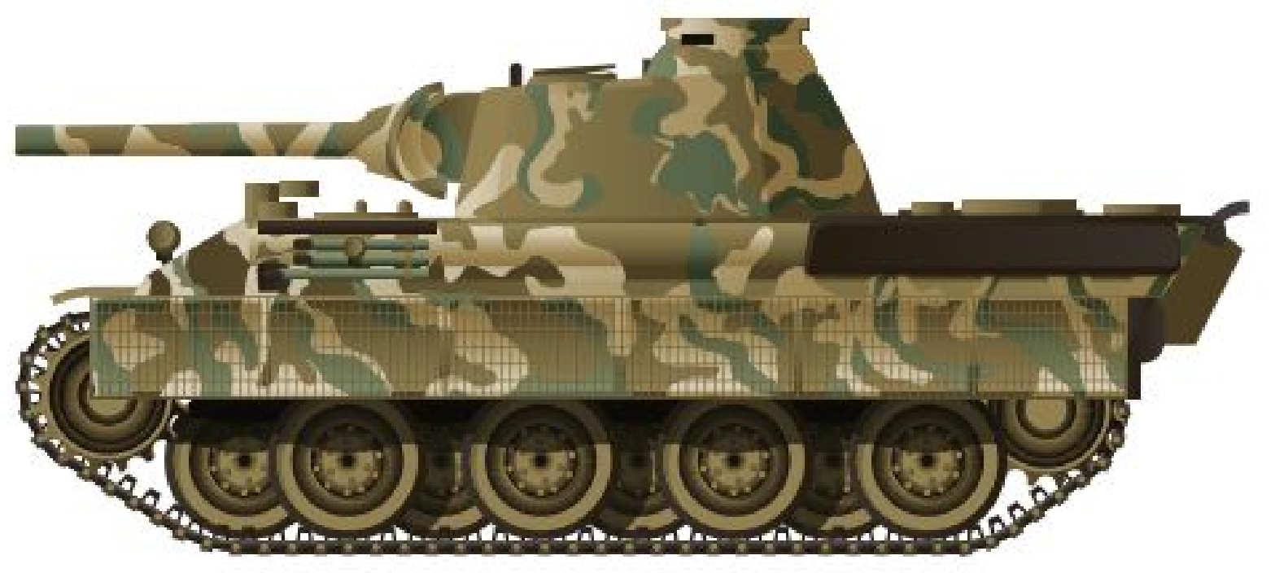
PANZER I
1934
Small, nimble and lightly armed with two machine-guns, these tanks were manned by just two crew members.



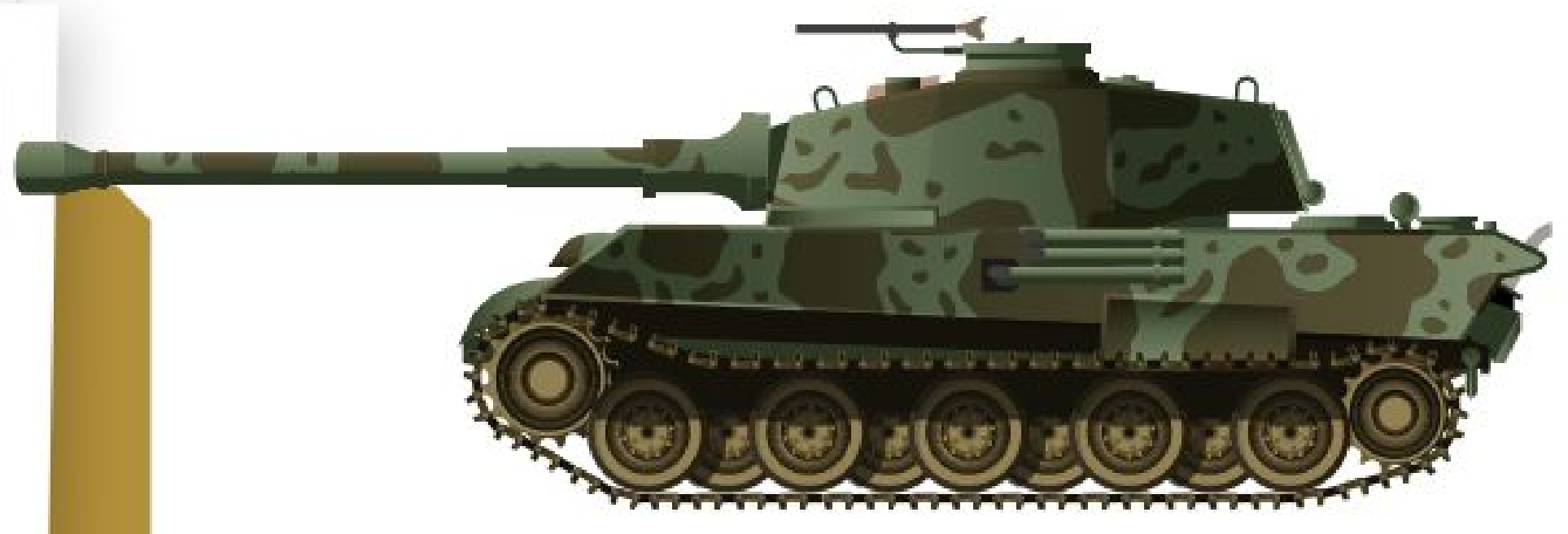
PANZER IV
1937
Fitted with a 75mm turret cannon, this was the most numerous German tank during WWII, with over 8,000 produced.



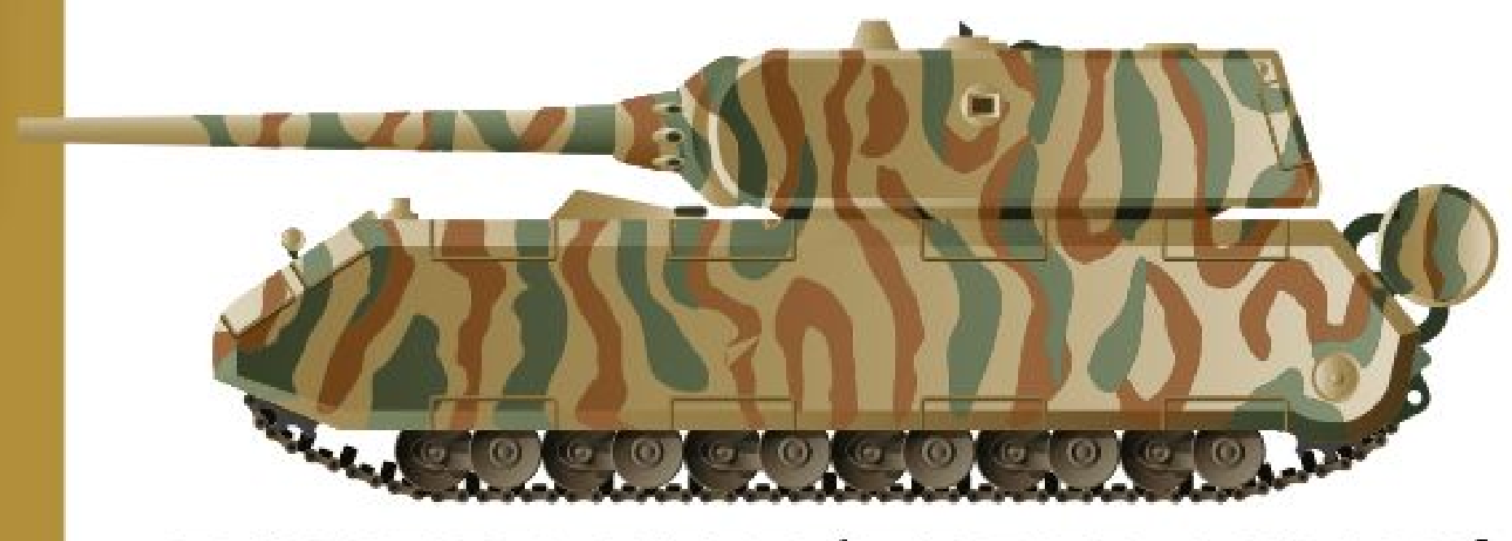
TIGER I
1942
With a huge 88mm gun, the Tiger I favoured firepower over the greater manoeuvrability of the Panther.



PANZER V PANTHER
1943
Developed to tip the balance on the Eastern Front, its sloped armour plating increased its effectiveness against horizontal ballistics.



TIGER II
1944
The King Tiger combined the effective sloped armour of the Panther with an improved 88mm cannon.



PANZER VIII 'TIGER MAUS'
1944-5
The 'super heavy' Tiger II successor would have carried a 128mm cannon, with 250mm sloped armour. The project was never completed.

© Illustrations by Ed Crooks; Osprey; Getty

Florence Cathedral

This iconic building is the result of centuries of Italian artistry and a mind-boggling architectural achievement

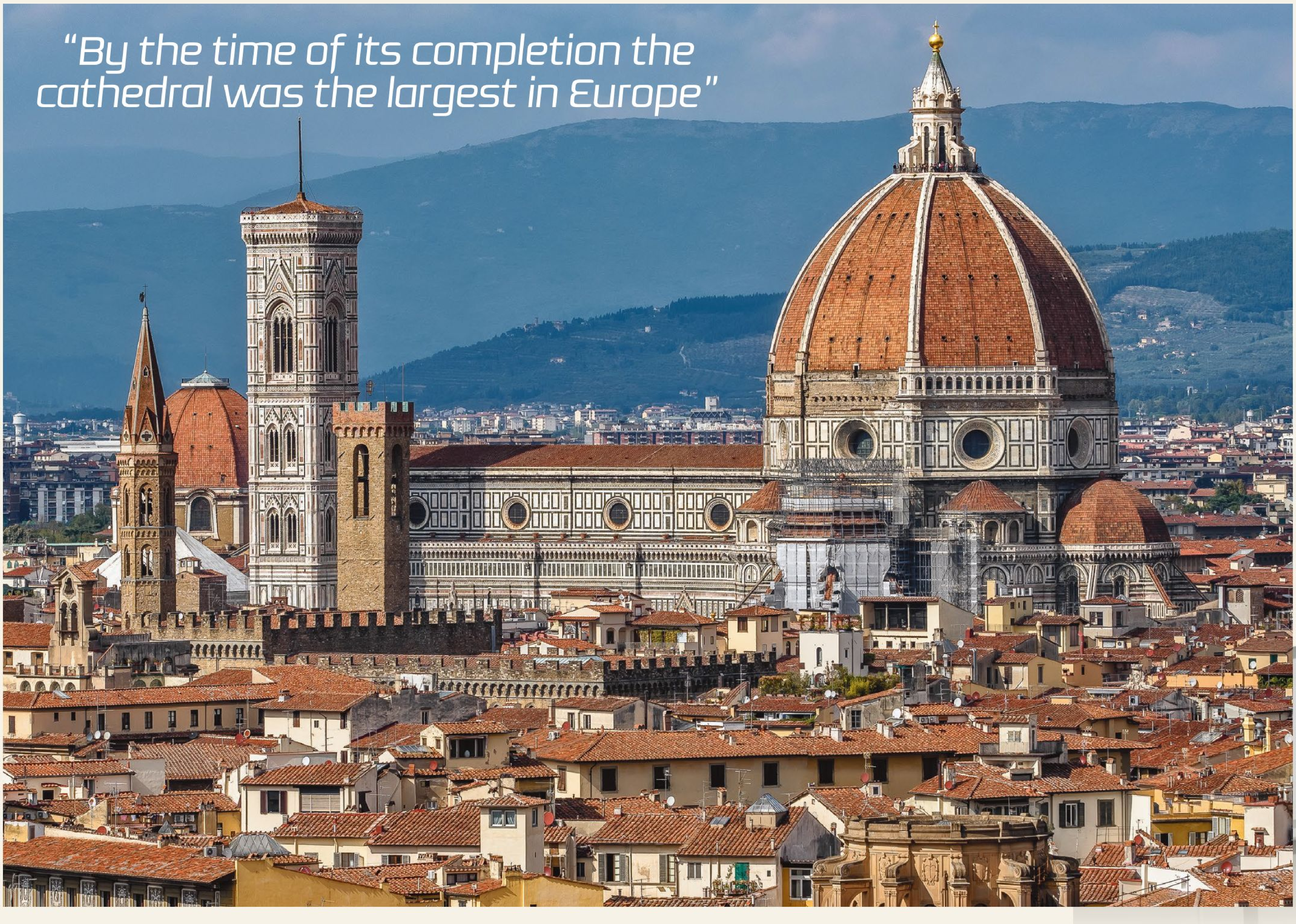
In 1294 the leaders of Florence decided to build a grand cathedral, not only to reflect the huge success and prestige of the city but also to compete with its rivals, such as Milan and Venice. Work began two years later around the existing church of Santa Reparata. The new cathedral was to be called Santa Maria del Fiore (Saint Mary of the Flower), echoing the traditional name of Florence: Fiorenza. Today it is commonly referred to simply as 'Il Duomo'.

One of the first items on the Florentine council's wish list was a large bell tower, which was designed by master builder Giotto di Bondone. At nearly 85 metres tall, this grand design dominated the Florentine skyline when it was completed in 1359 and dwarfed a certain tower in neighbouring Pisa (which stands at 57 metres tall). Its seven huge bells weigh over 10 tons – more than enough to wake sleepy Florentines for mass. Unfortunately, Giotto never saw the completion of his vision as he died just three years into the project, leaving his assistant Andrea Pisano to continue his work.

Yet another ambitious architect by the name of Francesco Talenti took charge of the project after Pisano's death in 1348 and set about enlarging the original plans. The new nave (the central walkway), along with its vaulting ceiling and aisles, were completed in 1380. By this time the new Gothic-style walls had entirely enveloped the old Santa Reparata, and the old building was finally demolished.

In the 15th century, Florence's most talented sculptors were commissioned to carve out marble statues to decorate the exterior structure, depicting biblical figures as well as the city's most influential citizens. At the time of its completion the cathedral was the largest in Europe. Today it is part of a UNESCO World Heritage Site, embodying centuries of artistic and architectural eras.

The emblem 'OPA' on the cathedral floor represents Opera del Duomo, the organisation behind its construction



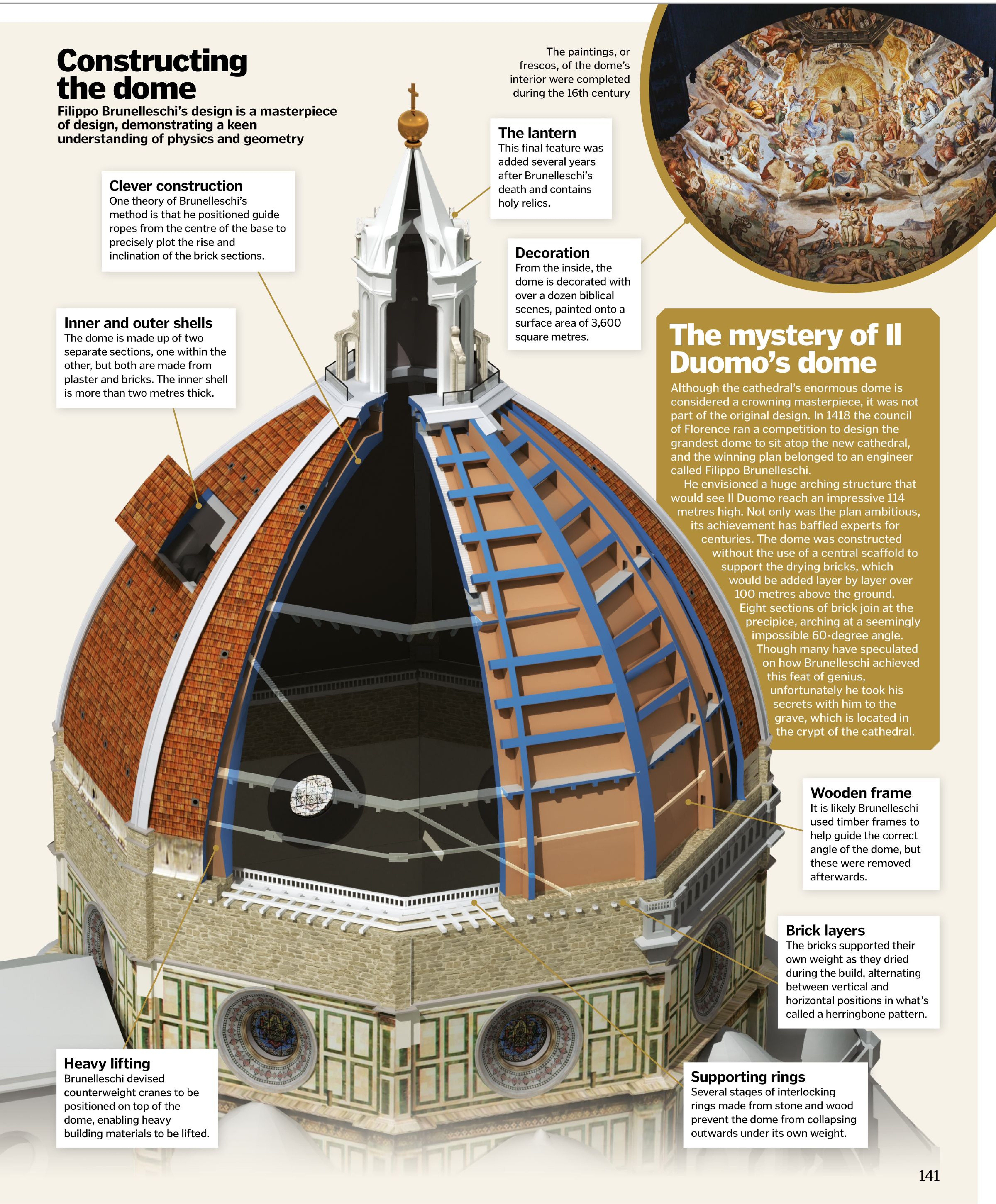
"By the time of its completion the cathedral was the largest in Europe"

© Getty; Alamy; Illustration by Adrian Mann

DID YOU KNOW? *With a diameter of over 45 metres, the cathedral dome is still the largest masonry dome in the world*

Constructing the dome

Filippo Brunelleschi's design is a masterpiece of design, demonstrating a keen understanding of physics and geometry



The paintings, or frescos, of the dome's interior were completed during the 16th century

The lantern
This final feature was added several years after Brunelleschi's death and contains holy relics.

Clever construction
One theory of Brunelleschi's method is that he positioned guide ropes from the centre of the base to precisely plot the rise and inclination of the brick sections.

Decoration
From the inside, the dome is decorated with over a dozen biblical scenes, painted onto a surface area of 3,600 square metres.

Inner and outer shells
The dome is made up of two separate sections, one within the other, but both are made from plaster and bricks. The inner shell is more than two metres thick.

Wooden frame
It is likely Brunelleschi used timber frames to help guide the correct angle of the dome, but these were removed afterwards.

Brick layers
The bricks supported their own weight as they dried during the build, alternating between vertical and horizontal positions in what's called a herringbone pattern.

Heavy lifting
Brunelleschi devised counterweight cranes to be positioned on top of the dome, enabling heavy building materials to be lifted.

Supporting rings
Several stages of interlocking rings made from stone and wood prevent the dome from collapsing outwards under its own weight.

The mystery of Il Duomo's dome

Although the cathedral's enormous dome is considered a crowning masterpiece, it was not part of the original design. In 1418 the council of Florence ran a competition to design the grandest dome to sit atop the new cathedral, and the winning plan belonged to an engineer called Filippo Brunelleschi.

He envisioned a huge arching structure that would see Il Duomo reach an impressive 114 metres high. Not only was the plan ambitious, its achievement has baffled experts for centuries. The dome was constructed without the use of a central scaffold to support the drying bricks, which would be added layer by layer over 100 metres above the ground.

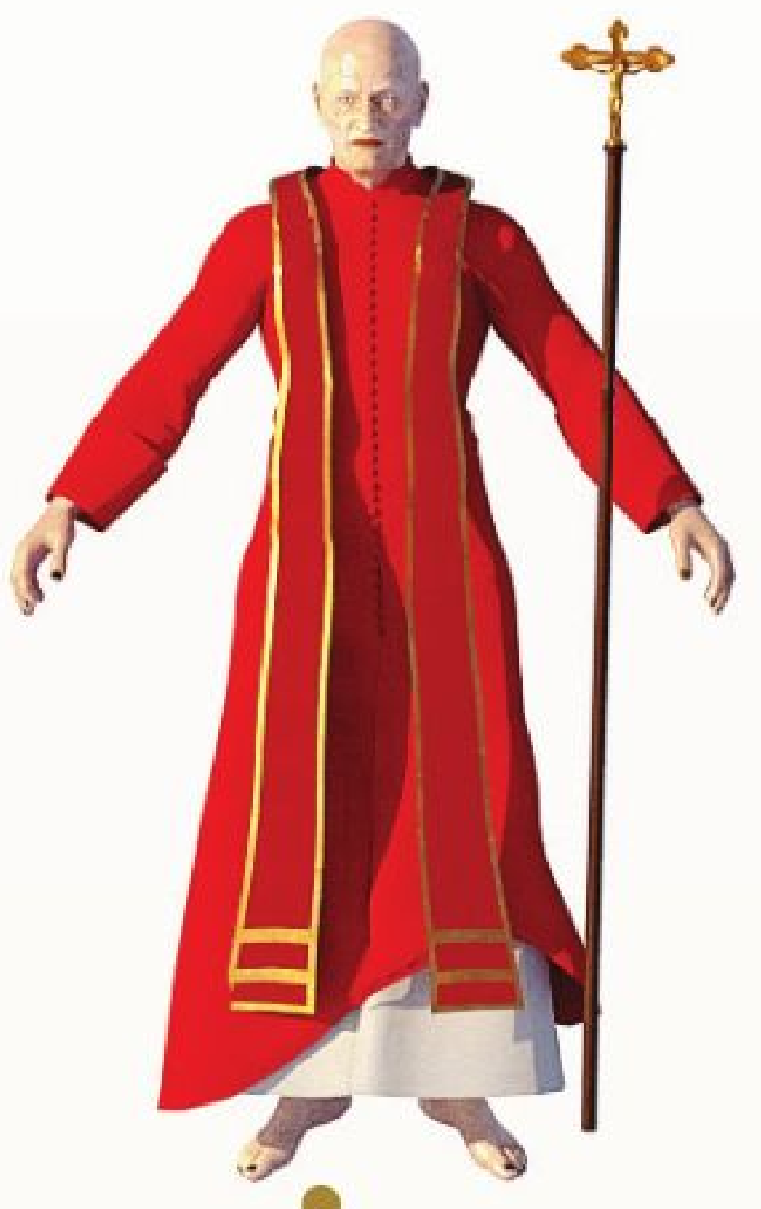
Eight sections of brick join at the precipice, arching at a seemingly impossible 60-degree angle. Though many have speculated on how Brunelleschi achieved this feat of genius, unfortunately he took his secrets with him to the grave, which is located in the crypt of the cathedral.

Picking the Pope

Electing the new pontiff is a process steeped in religious ceremony, ritual and secrecy

By tradition, the College of Cardinals (called the conclave) meet to elect the new Pope, who is also referred to as the successor to Saint Peter, Christ's vicar on Earth, the Bishop of Rome, and today is the head of a congregation numbering over 1 billion people.

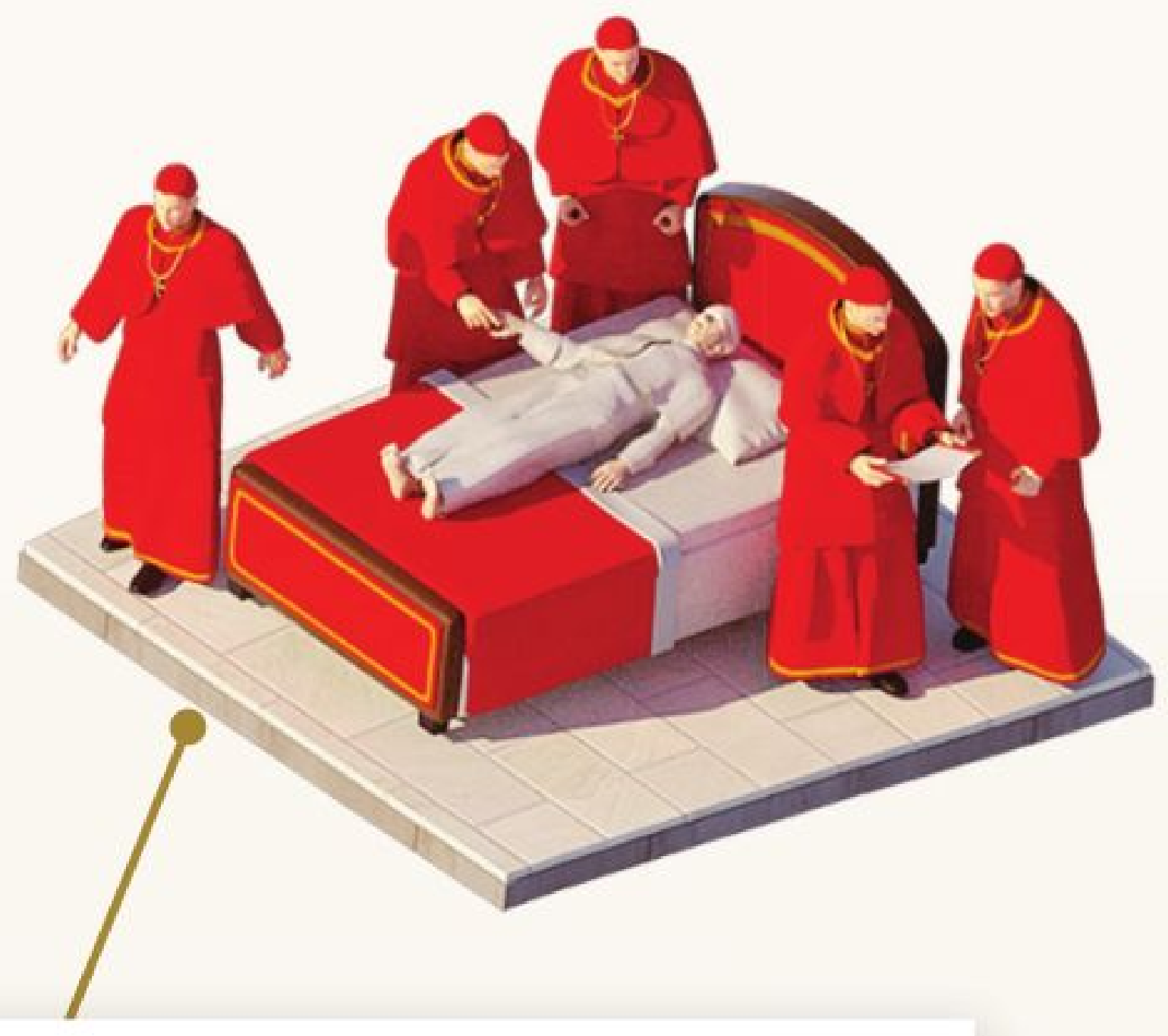
For centuries each conclave has gathered inside the Vatican palaces, which are locked down to prevent anyone outside the conclave influencing the vote. During the Conclave of 1484, cardinals were even forced to eat and sleep in the cramped conditions of the Sistine Chapel. Despite these measures, vote-buying and other tactics were suspected in several conclaves. The historic power struggles, alliances, factions and intrigues of European politics were often at work at these gatherings. Although no such devious dealings are known to continue in the modern era, the conclave remains a private process, with rigorous checks and balances.



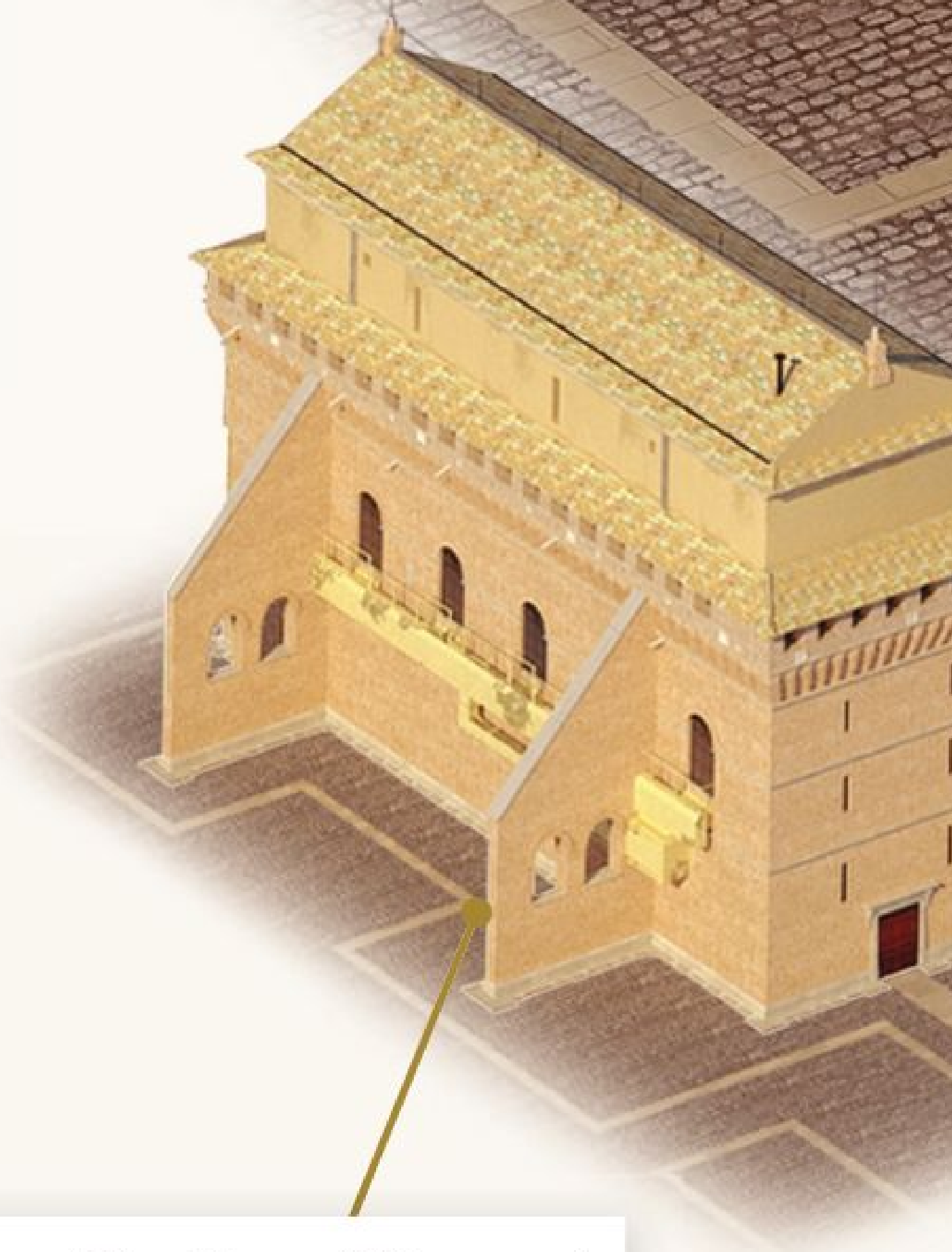
Mourning
Starting from the day of the Pope's funeral, the Vatican begins nine days of mourning, with mass held on each day. The body is dressed in ceremonial robes.

The Conclave

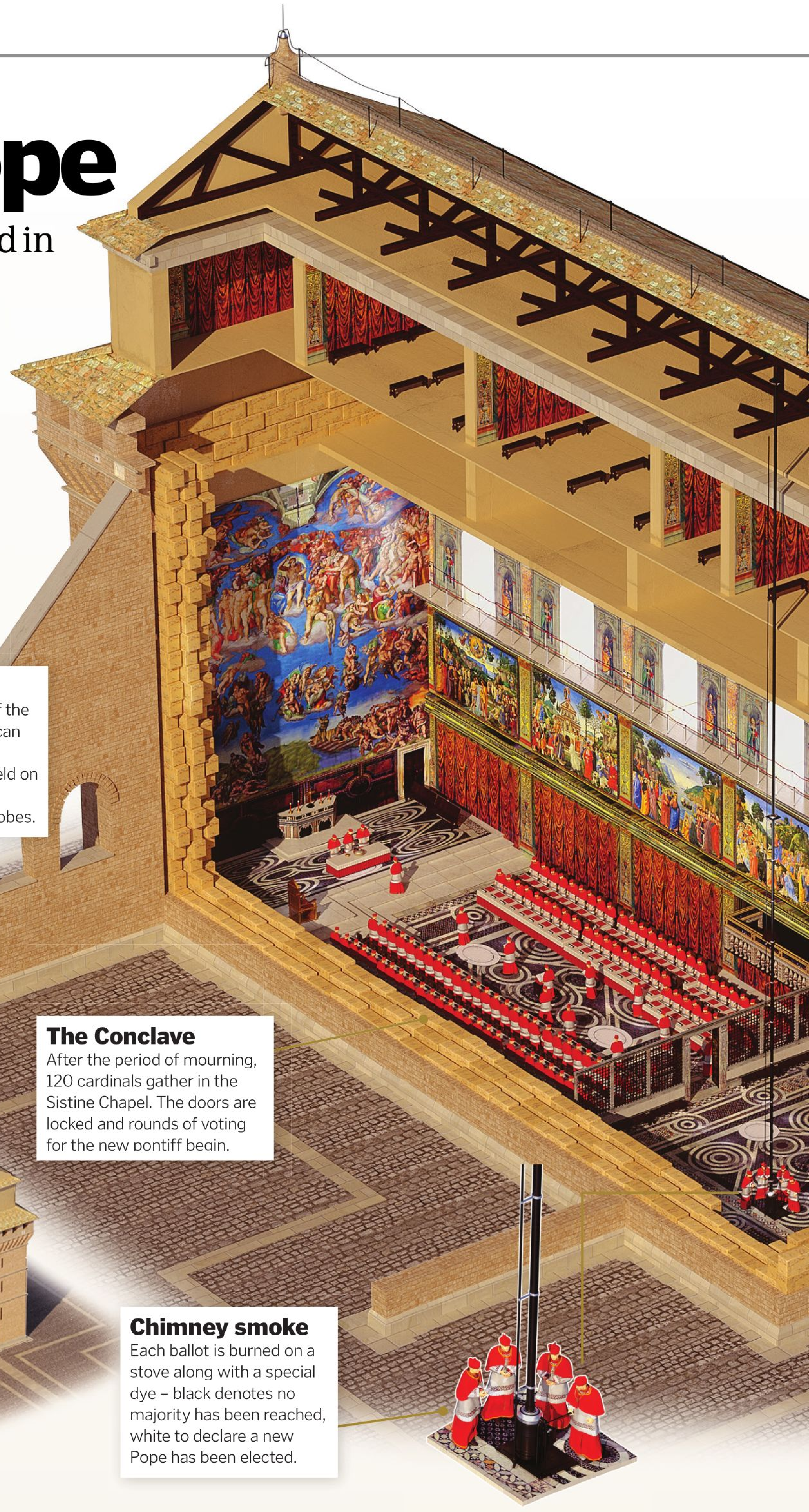
Held behind closed doors, the papal election follows a strict and secretive procedure



Death of the pontiff
When the incumbent Pope has been declared deceased, or in rare occasions announces his retirement, the College of Cardinals are summoned to the Vatican.



The Sistine Chapel



The Conclave
After the period of mourning, 120 cardinals gather in the Sistine Chapel. The doors are locked and rounds of voting for the new pontiff begin.

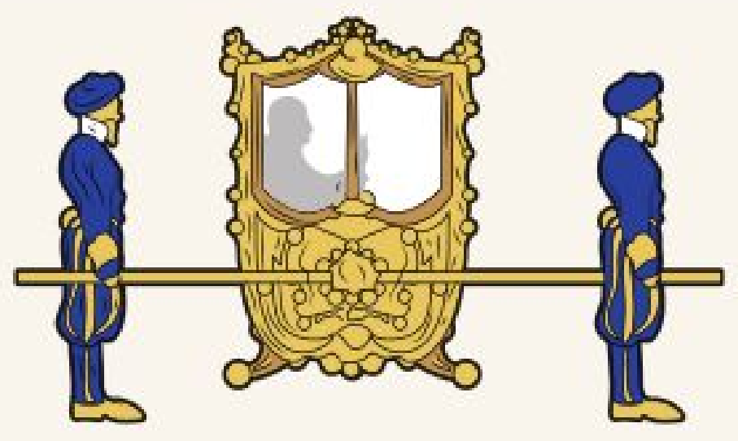
Chimney smoke
Each ballot is burned on a stove along with a special dye – black denotes no majority has been reached, white to declare a new Pope has been elected.

Pope mobiles through the years

For decades the pontiff has used a range of transport solutions to keep him mobile

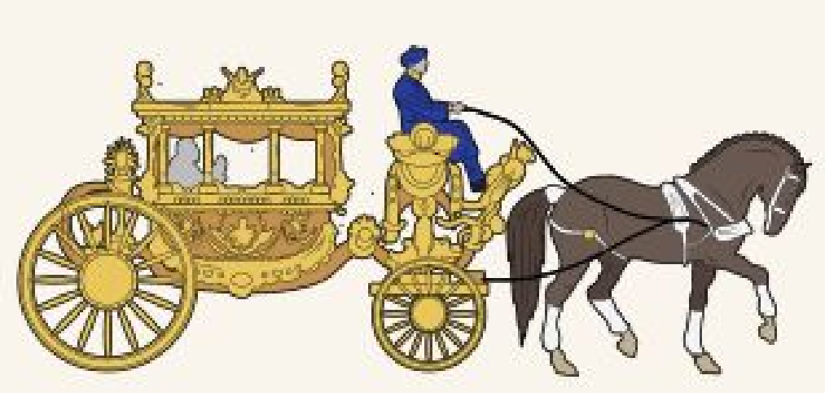
1878-1903

Sedan Chair – Leo XIII
During the 19th century popes would be carried around inside these highly decorated enclosed or open-air chairs by guards.



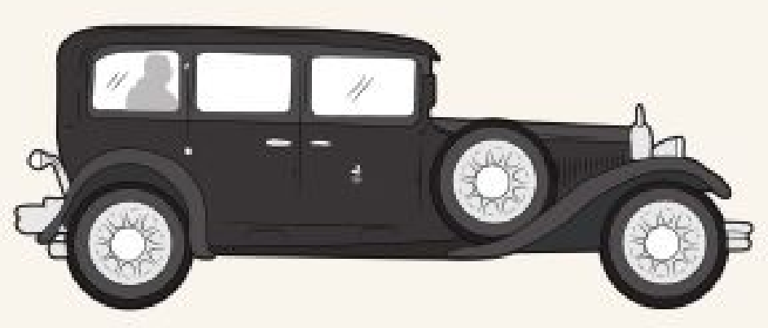
1800s

Carriage – Various
Throughout the 19th century horse-drawn carriages were used, upholstered with red velvet and decorated with gilded engravings.



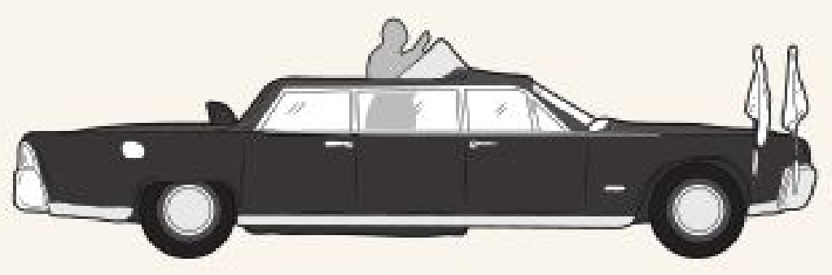
1930

Mercedes-Benz Nürburg 460 – Pius XI
This model came with a bespoke crimson rear passenger seat and was even test-driven by Pius XI himself.



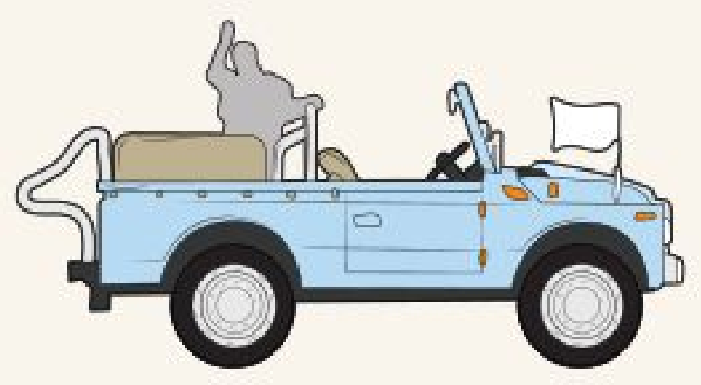
1965

Lincoln Continental – Paul VI
This six-metre limo came complete with a specially designed roof windshield and a crank to raise the Pope's seat higher.



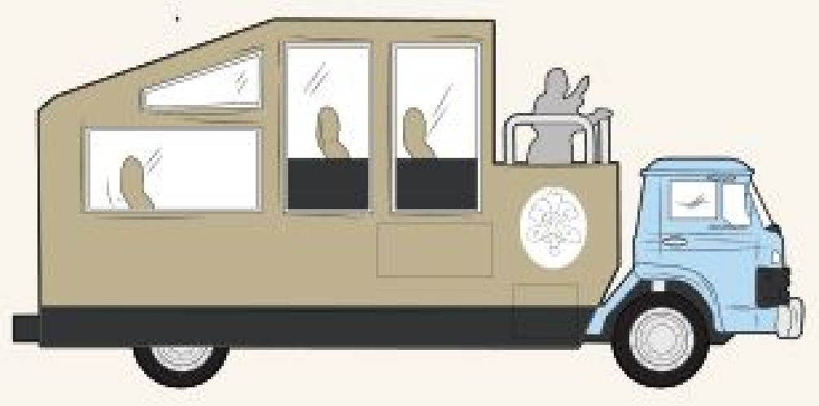
1978-2005

Fiat Campagnola – Paul VI, John Paul II
In May 1981 John Paul II was riding in this open-topped 4x4 when he was shot.



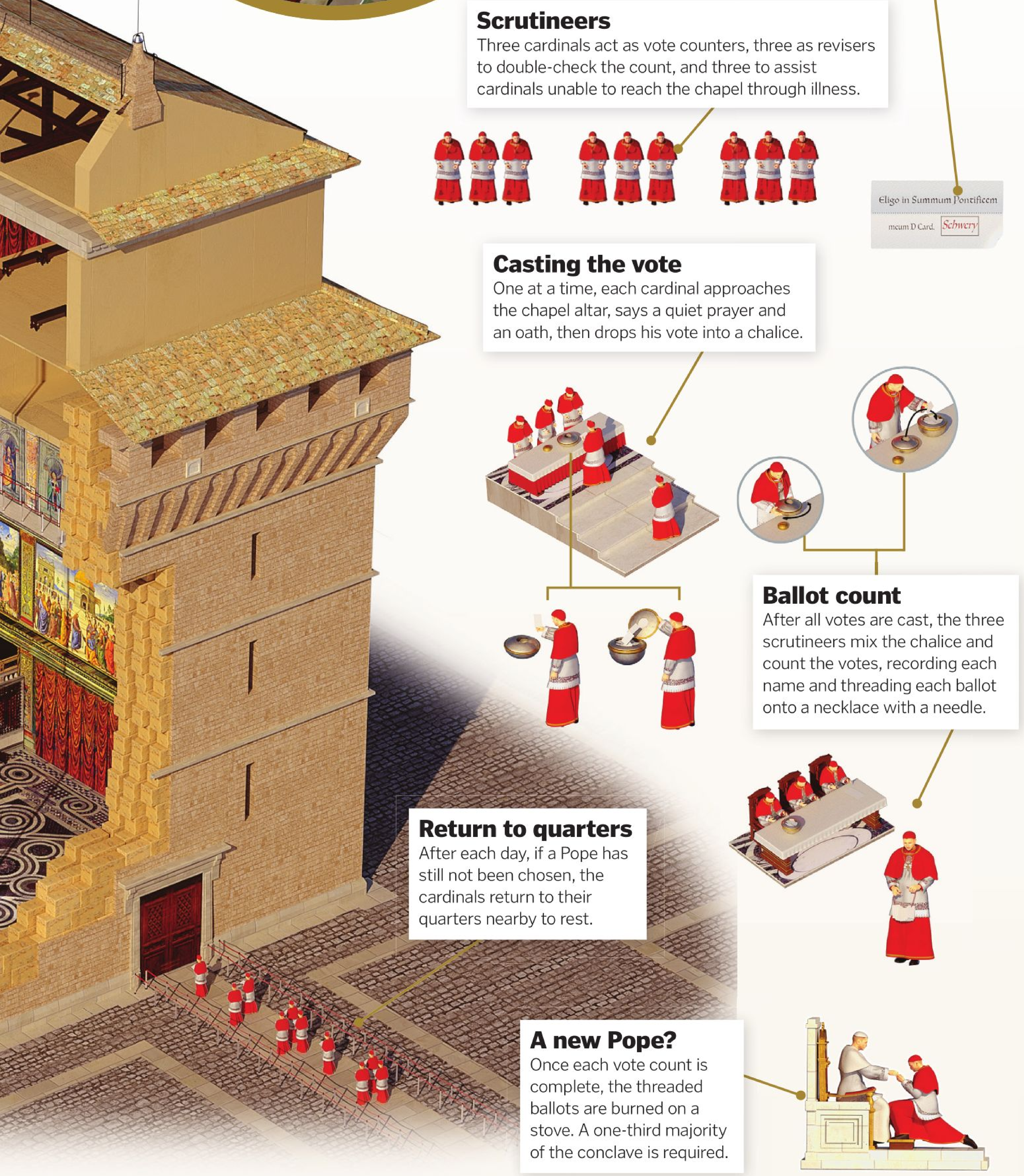
1979

Ford D-Series – John Paul II
This transformed truck is surrounded with shatterproof glass and has enough room to accommodate 16.



DID YOU KNOW? *The Holy See owns the papal palace of Castel Gandolfo, a 17th-century villa located 25km southeast of Rome*

Cardinals gather in the Sistine Chapel for the 2013 conclave after the resignation of Benedict XVI



Voting card

Each cardinal writes the name of their chosen candidate on a small voting card, under the phrase 'Eligo in Summum Pontificem': 'I choose as supreme Pontiff'.

Scrutineers

Three cardinals act as vote counters, three as revisers to double-check the count, and three to assist cardinals unable to reach the chapel through illness.

Casting the vote

One at a time, each cardinal approaches the chapel altar, says a quiet prayer and an oath, then drops his vote into a chalice.

Ballot count

After all votes are cast, the three scrutineers mix the chalice and count the votes, recording each name and threading each ballot onto a necklace with a needle.

Return to quarters

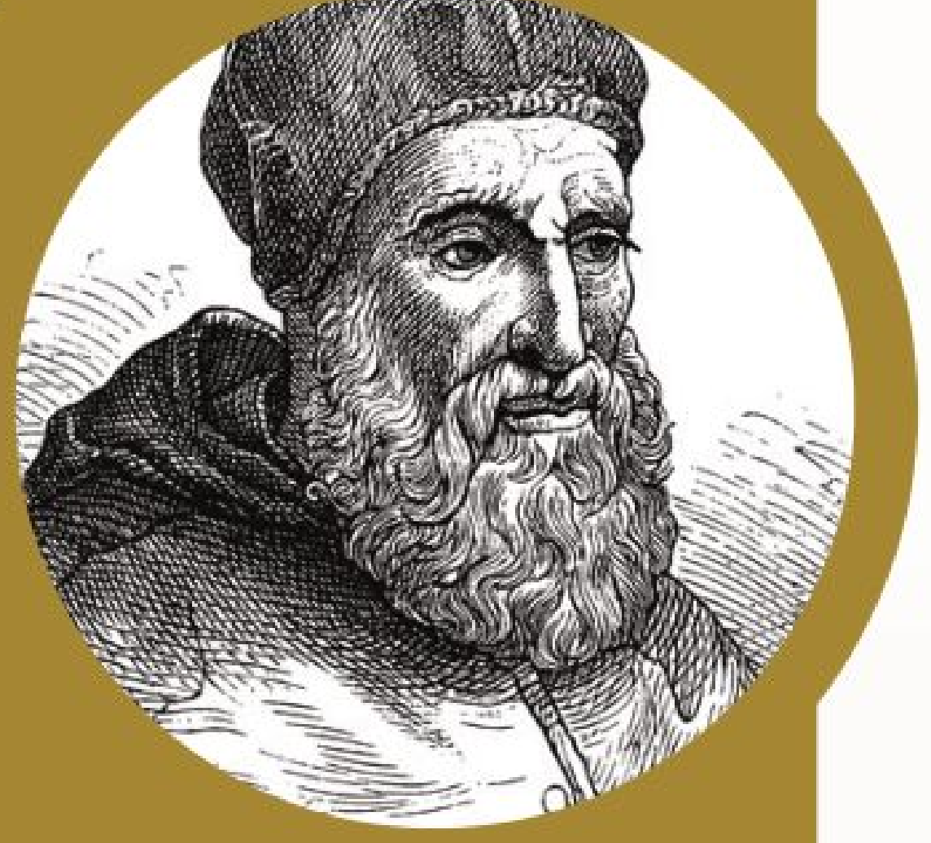
After each day, if a Pope has still not been chosen, the cardinals return to their quarters nearby to rest.

A new Pope?

Once each vote count is complete, the threaded ballots are burned on a stove. A one-third majority of the conclave is required.

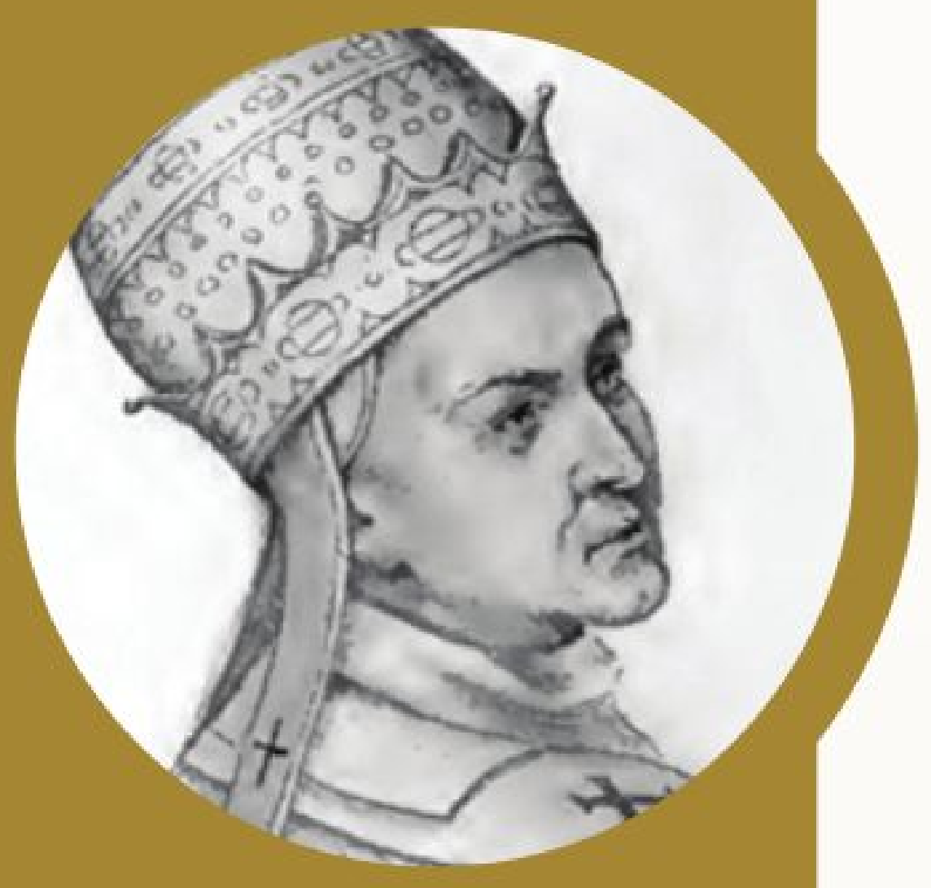
5 WORST POPES

Paul IV: 'The Zealot'



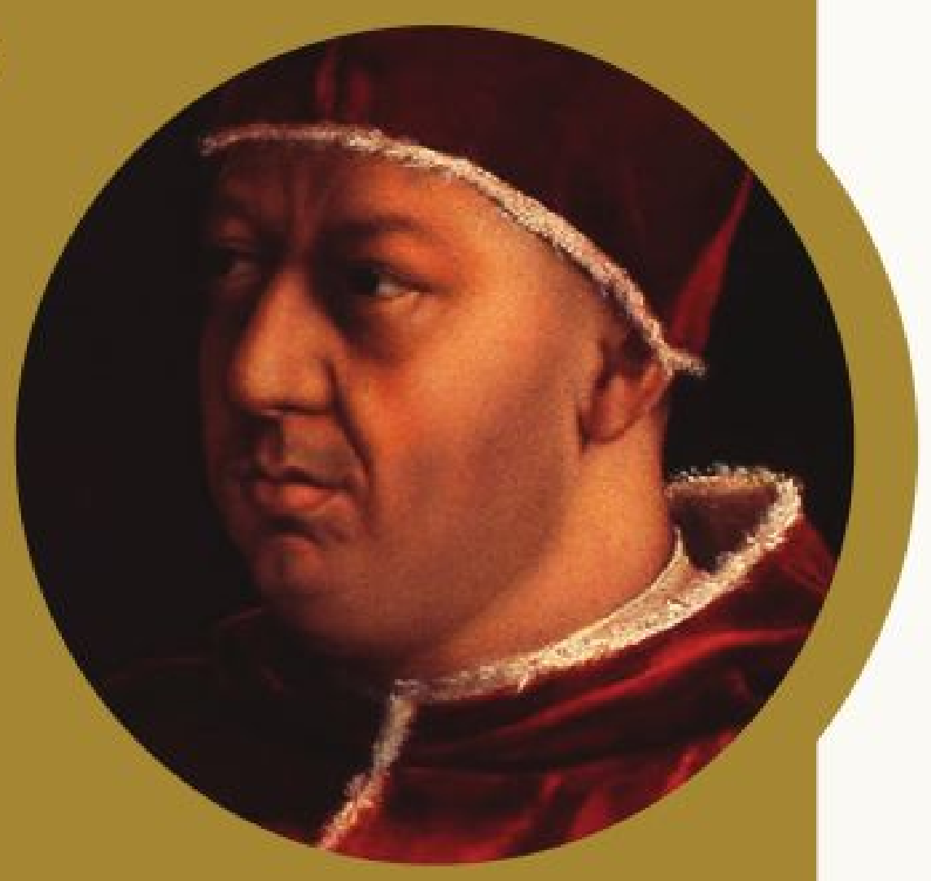
Creator of the Roman Inquisition, which ruthlessly hunted down and brutally punished accused heretics, Paul IV also burned hundreds of supposedly blasphemous books and also severely persecuted Rome's Jewish population.

Benedict IX: 'The Scandalous'



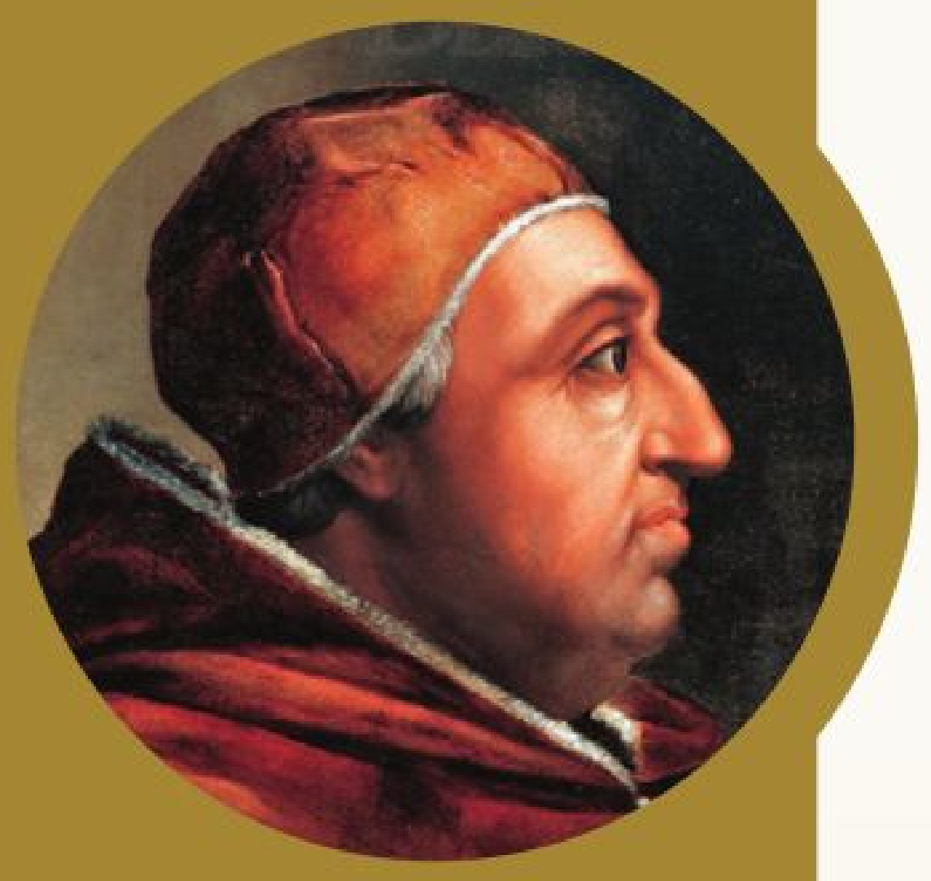
Made Pope on three separate occasions, Benedict engaged in multiple relationships (forbidden for priests) and even sold the title so that he could marry. After conspiring his way back into power, he was finally deposed in 1049 CE.

Leo X: 'The Greedy'



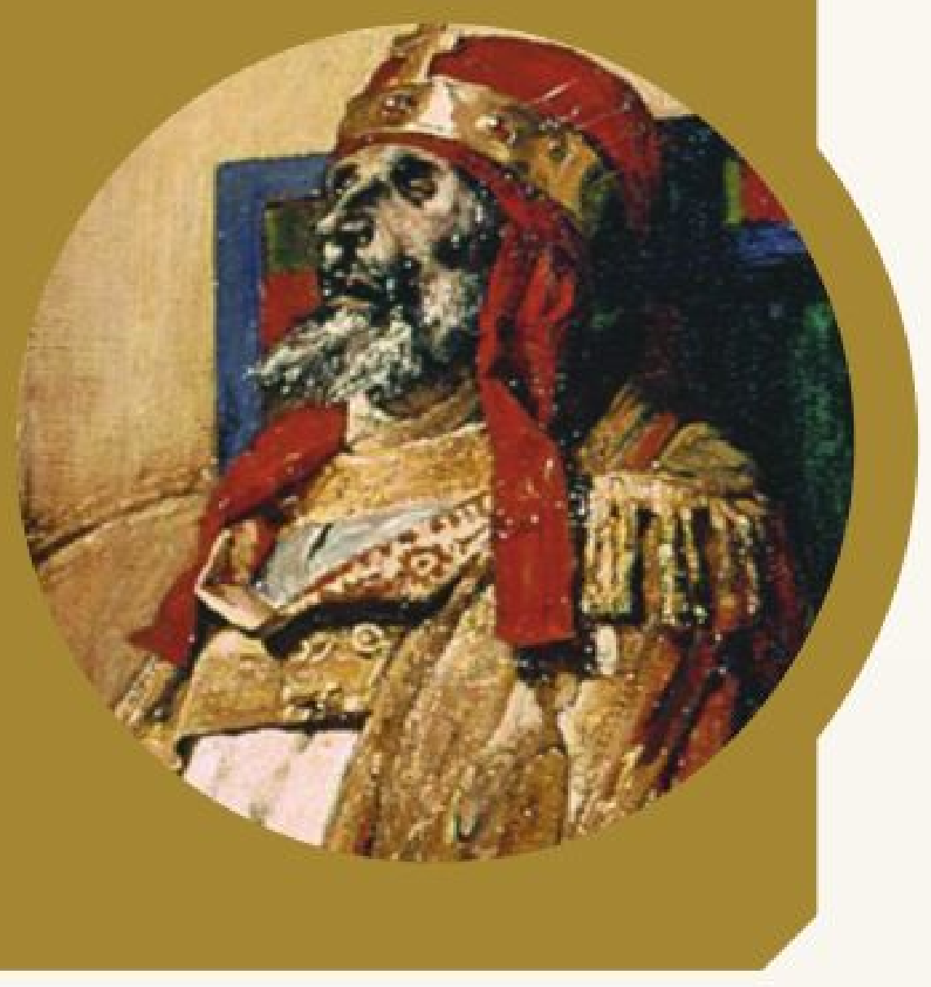
Leo enacted the sale of 'Indulgences' in the church, essentially taking payment in exchange for absolving, or reducing, the punishment for sins. This corrupt practice contributed to Martin Luther's Reformation.

Alexander VI: 'The Schemer'



Accused of bribing his way into power, Alexander also had several children and a secret wife. He made his teenage son a cardinal and used his position to strengthen his dynasty.

Stephen VI: 'The Avenger'

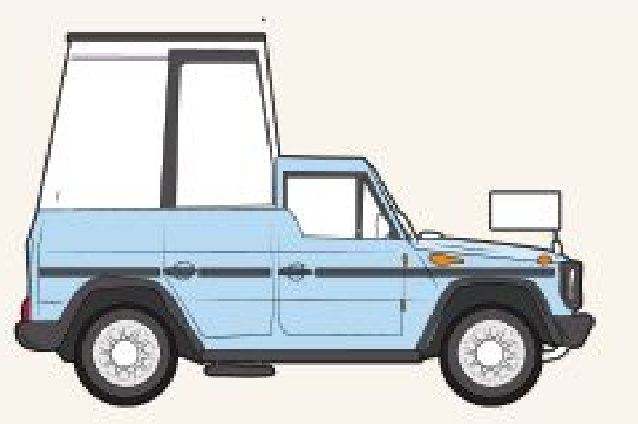


Stephen ordered that his dead predecessor, Pope Formosus, be dug up and put on trial for alleged corruption. He then had the body mutilated and dumped in the River Tiber.

1980-2012

Mercedes-Benz 230-G – John Paul II

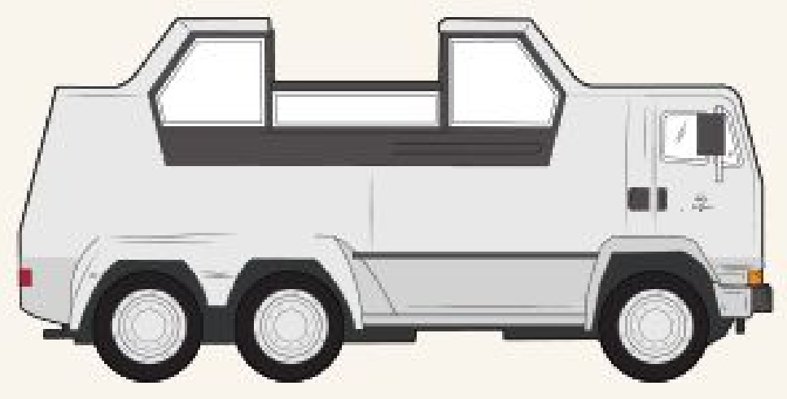
The special plexiglass bubble canopy on this vehicle was later made bulletproof for extra protection.



1982

Leyland Constructor – John Paul II

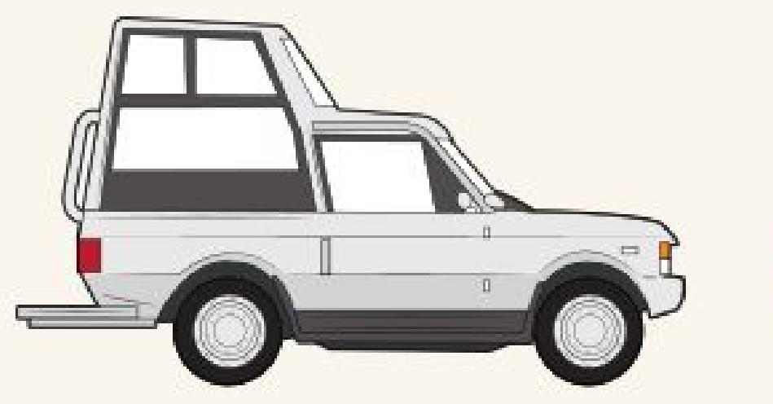
Designed for the Pope's 1982 visit to the UK, this truck weighed over 21,000 kilograms and took six weeks to build.



1982

Range Rover – John Paul II

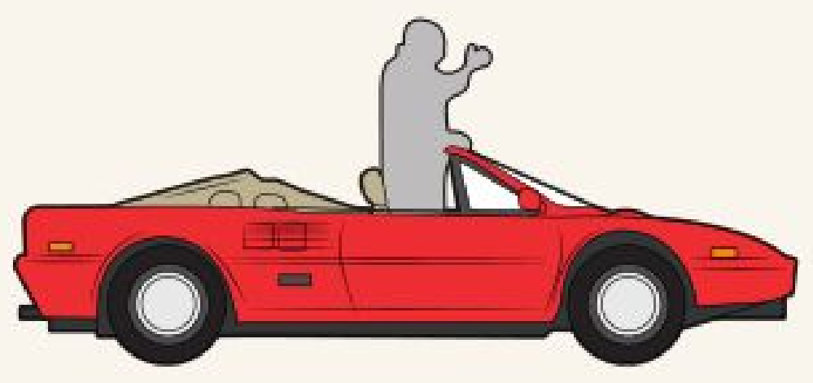
Another vehicle constructed for John Paul II's UK visit, this was among the first of the Popemobiles to feature bullet-resistant glass.



1988

Ferrari Mondial – John Paul II

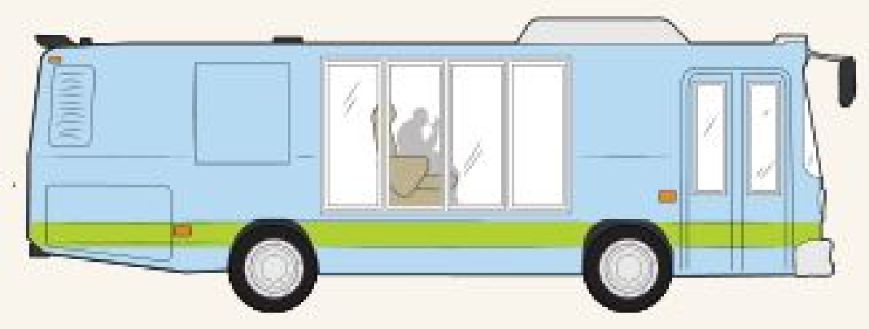
While on a visit to the Ferrari HQ in Maranello, northern Italy, the Holy Father went out for a spin in a Mondial convertible.



1999

Bus – John Paul II

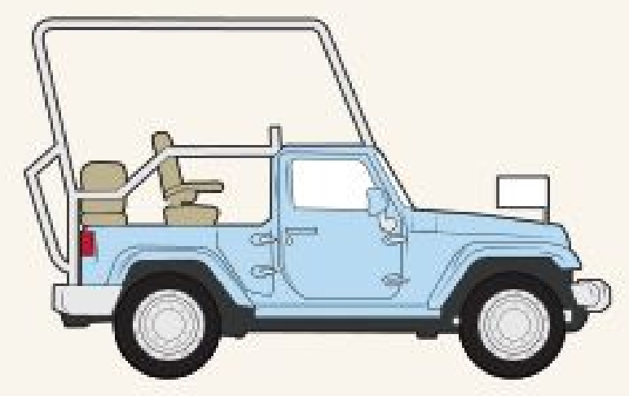
After serving its purpose during a 1999 visit to Mexico, this re-designed bus was turned into a permanent memorial.



2015

Jeep Wrangler – Francis

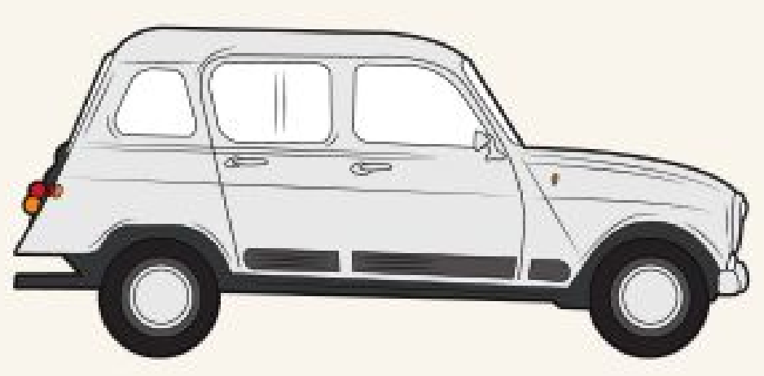
For the Pope's 2015 US visit, this robust 4x4 broke with tradition by dropping the bullet-resistant glass case.



2013 onward

1984 Renault 4 – Francis

The current Pope favours simplicity and drives himself around the Vatican in an old Renault with over 299,000 kilometres on the clock.



© Illustrations by Ed Crooks & Nicholas Forder. Alamy; Getty

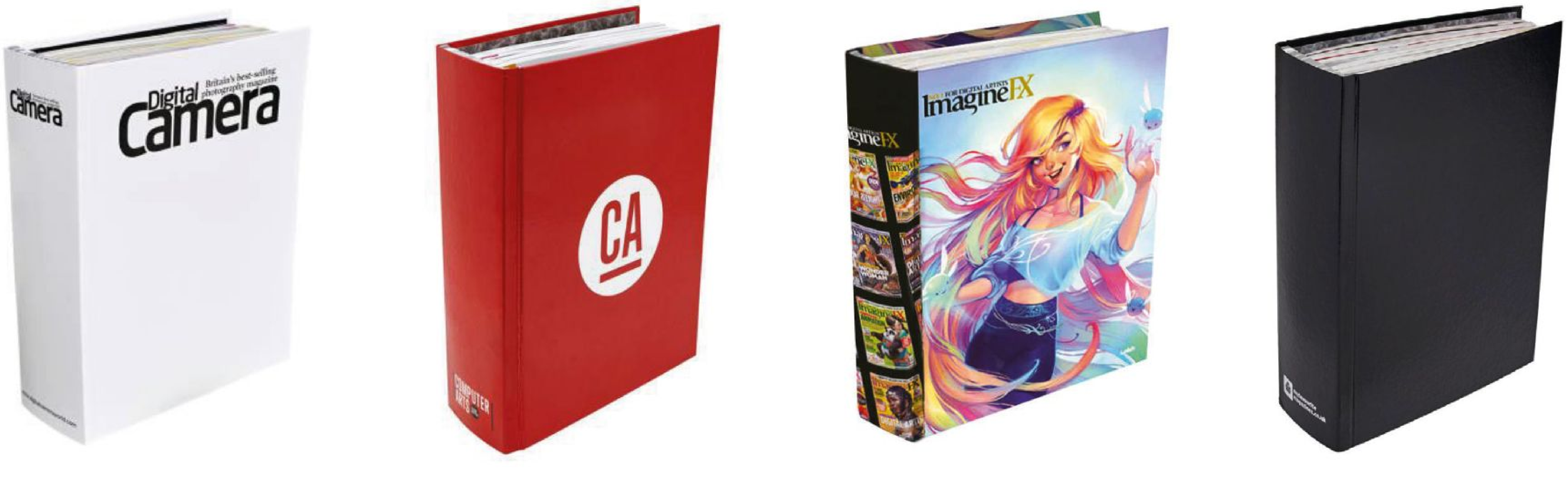
SUBSCRIBE AND SAVE UP TO 61%

Every issue of your subscription, delivered direct to your door. Print & digital editions available.

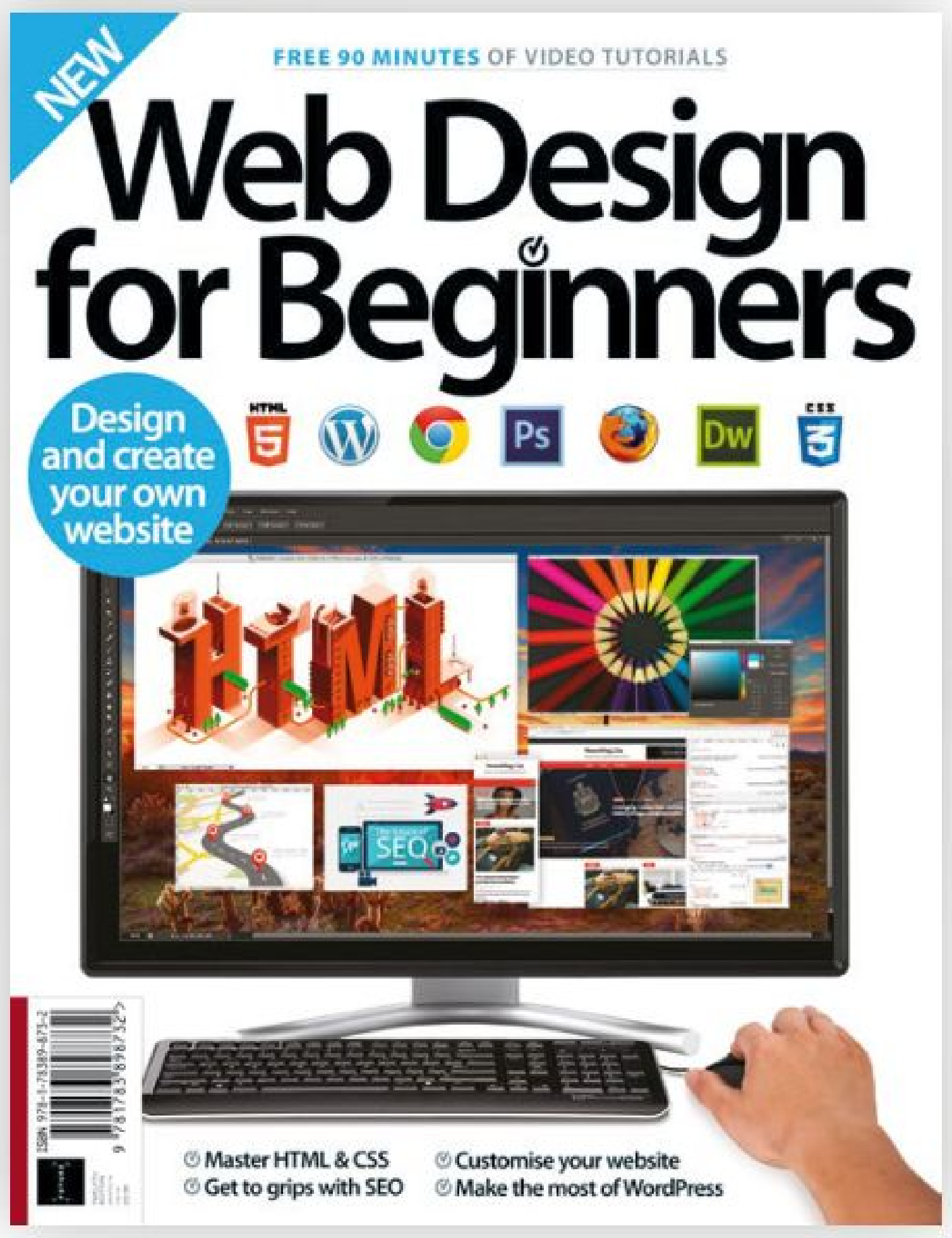
Classic Rock
Digital Photographer
FourFourTwo 2018
Total Film
History
EDGE
3D Artist
Linux Format

NEAT STORAGE

Store up to 13 issues of your magazine subscription in a coordinating slipcase or binder.


Digital Camera
CA
ImagineFX

myfavouritemagazines.co.uk


NEW
Web Design for Beginners
Design and create your own website

80s MOVIES
THE ULTIMATE CELEBRATION
THE HEROES! THE HITS! THE HAIR!

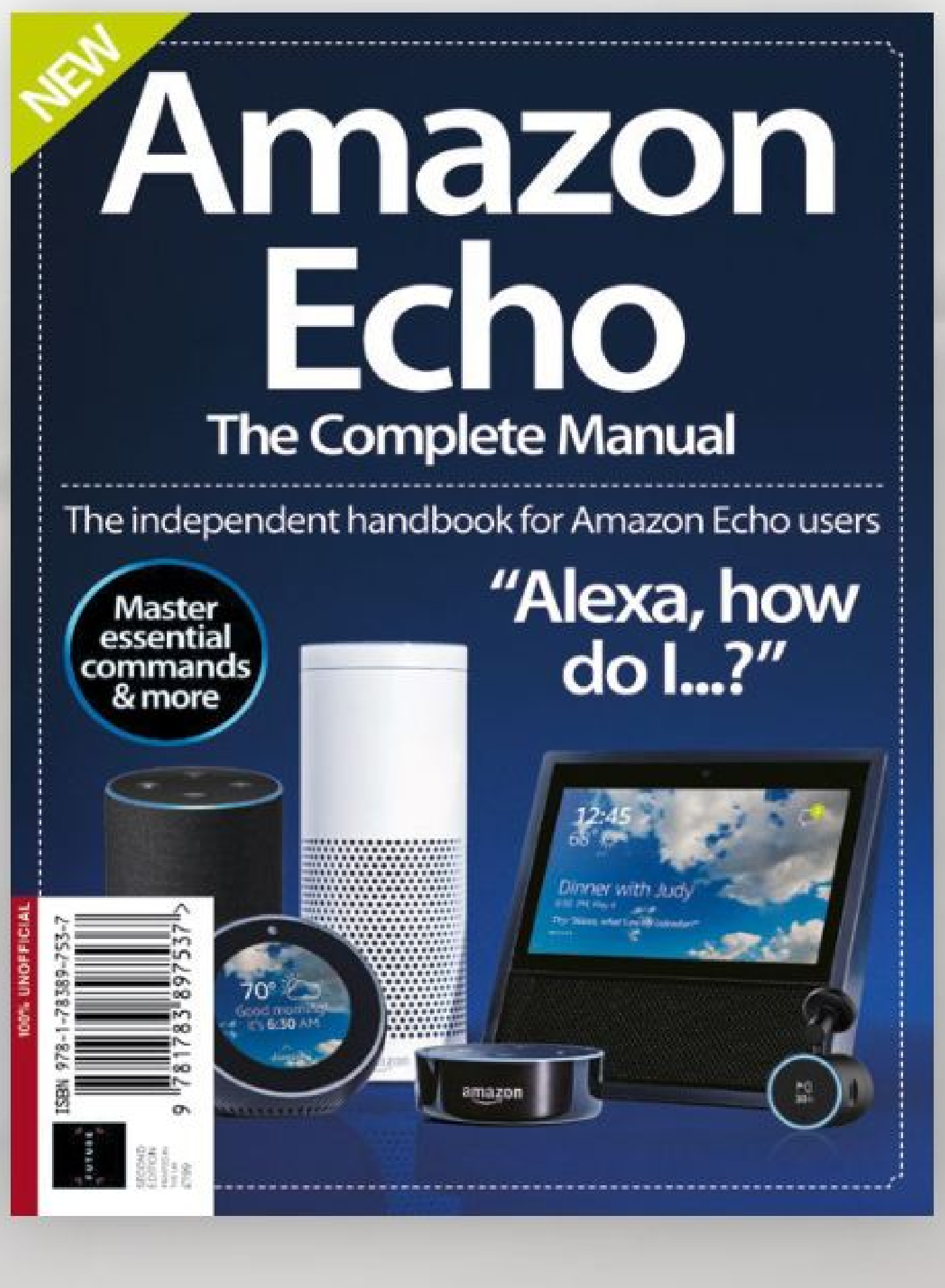
classic gaming
The ultimate guide to retro videogaming

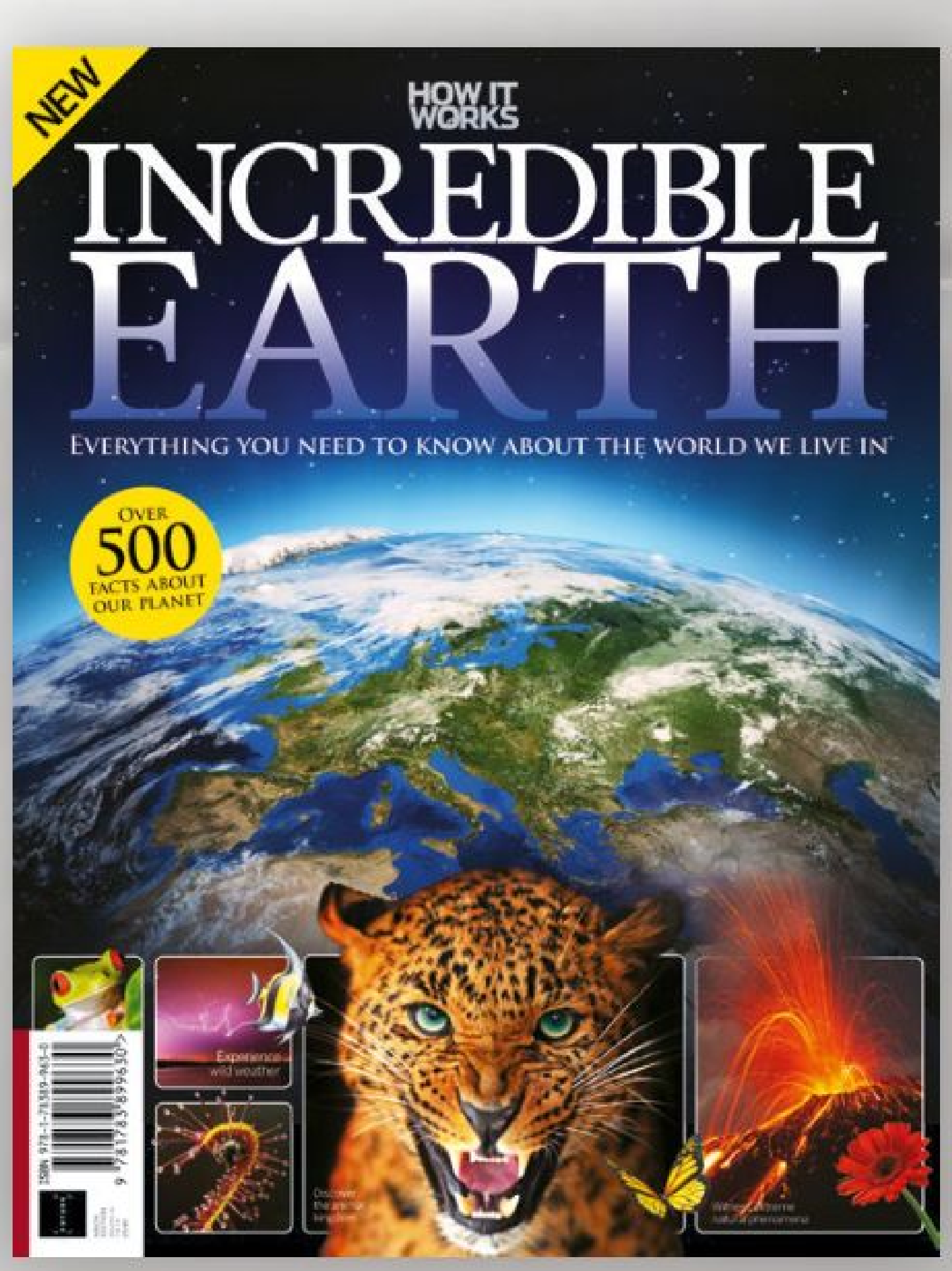
NEW
METALLICA
THE COMPLETE STORY
CLIFF BURTON REMEMBERED
EXCLUSIVE INTERVIEWS

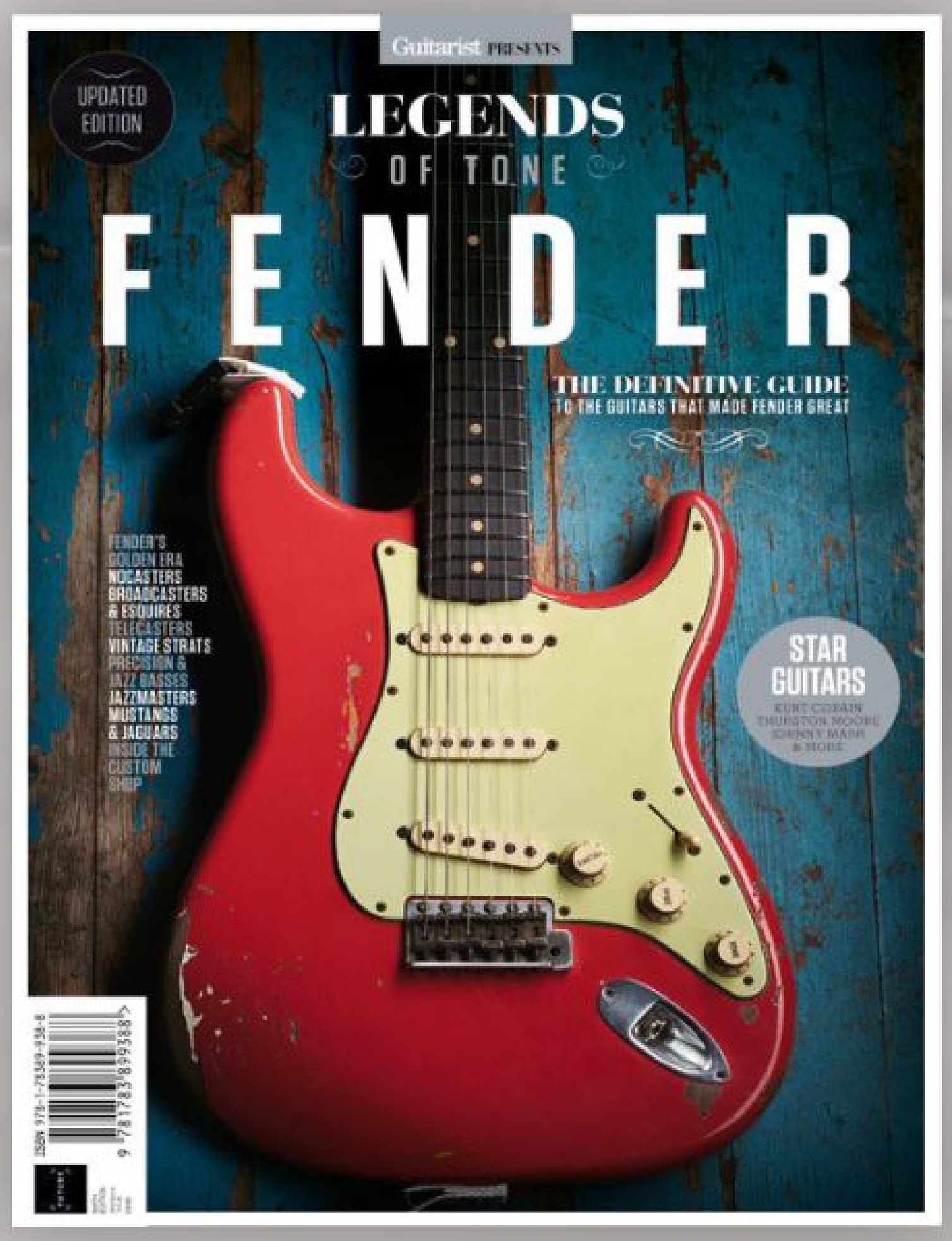
DISCOVER GREAT GUIDES & SPECIALS

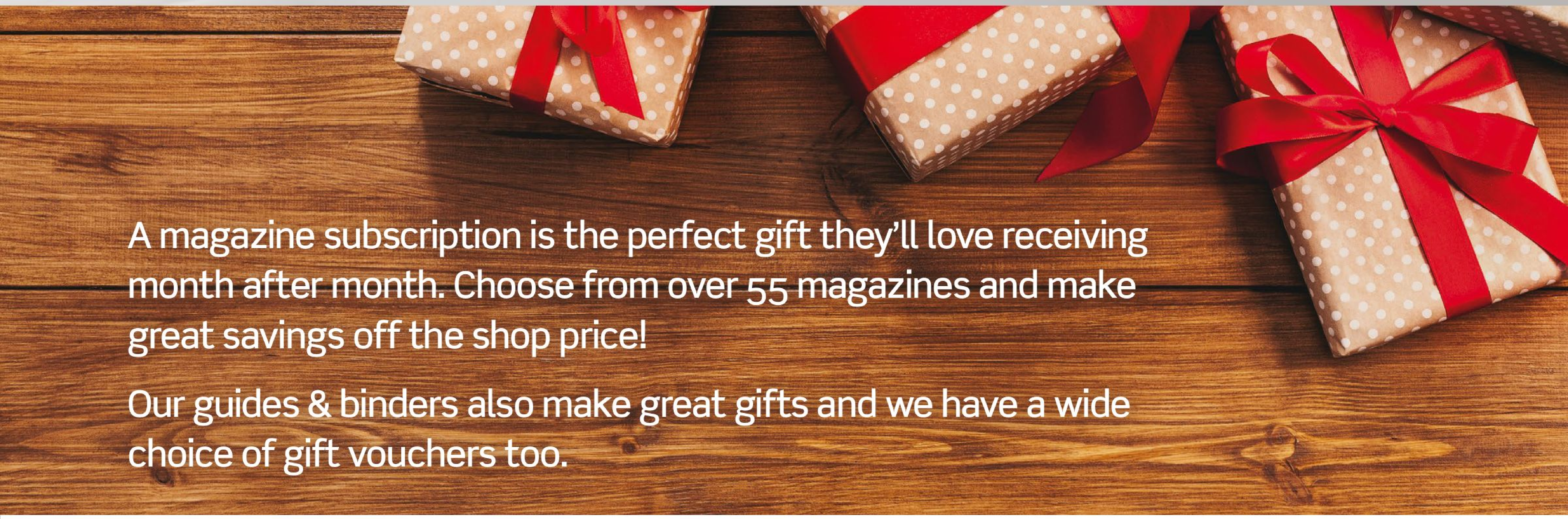
From photography to music and technology to gaming, there's something for everyone.

NEW
The Black & White Photography Book


NEW
Amazon Echo
The Complete Manual
"Alexa, how do I...?"


NEW
HOW IT WORKS
INCREDIBLE EARTH
OVER 500 FACTS ABOUT OUR PLANET


LEGENDS OF TONE
FENDER



A magazine subscription is the perfect gift they'll love receiving month after month. Choose from over 55 magazines and make great savings off the shop price!

Our guides & binders also make great gifts and we have a wide choice of gift vouchers too.

✓ No hidden costs Shipping included in all prices We deliver to over 100 countries Secure online payment

FUTURE

myfavouritemagazines
Official Magazine Subscription Store

Discover another of our great bookazines

From science and history to technology and crafts, there are dozens of Future bookazines to suit all tastes

✓ Get great savings when you buy direct from us

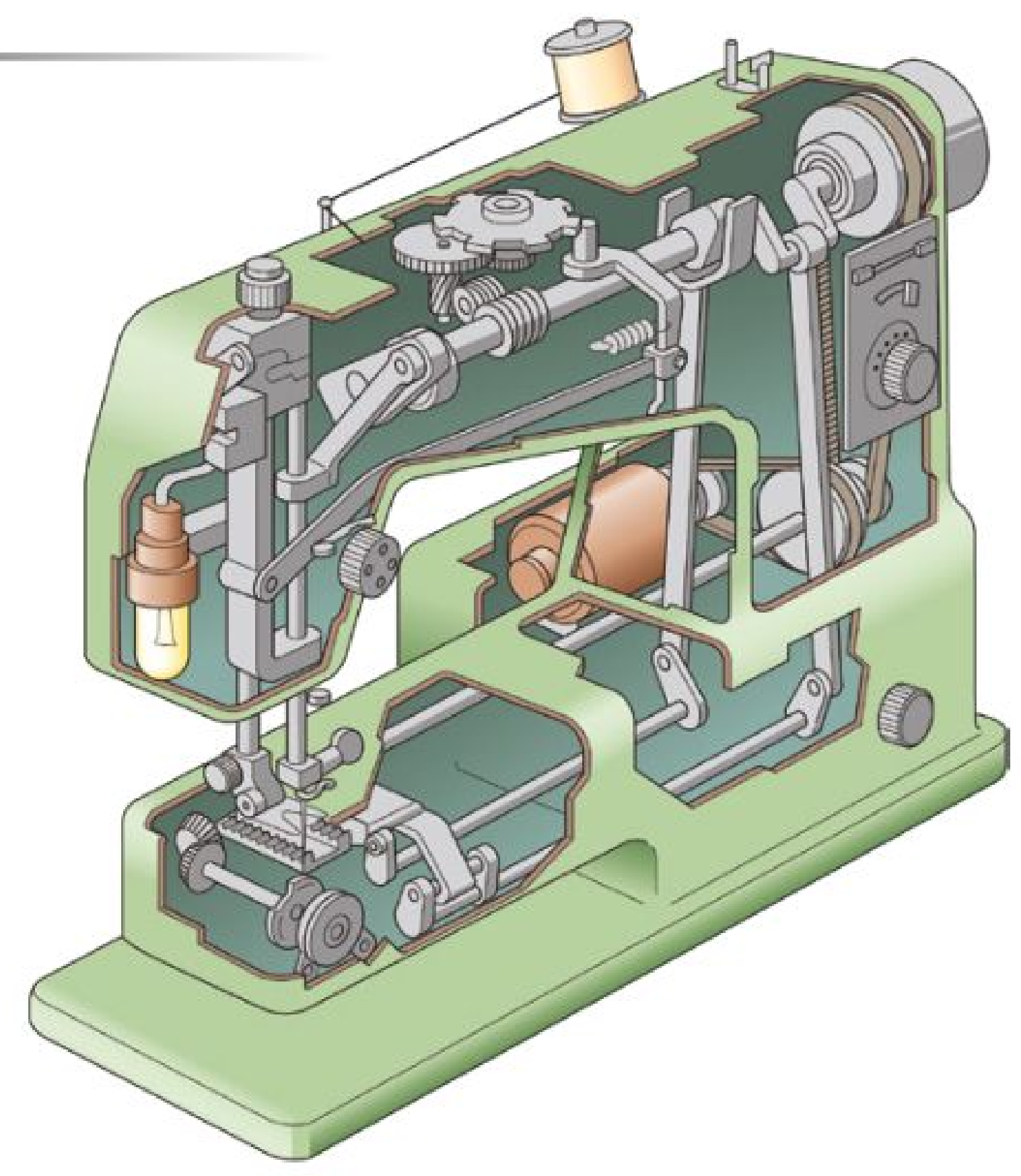
✓ 1000s of great titles, many not available anywhere else

✓ World-wide delivery and super-safe ordering

FUTURE

www.myfavouritemagazines.co.uk

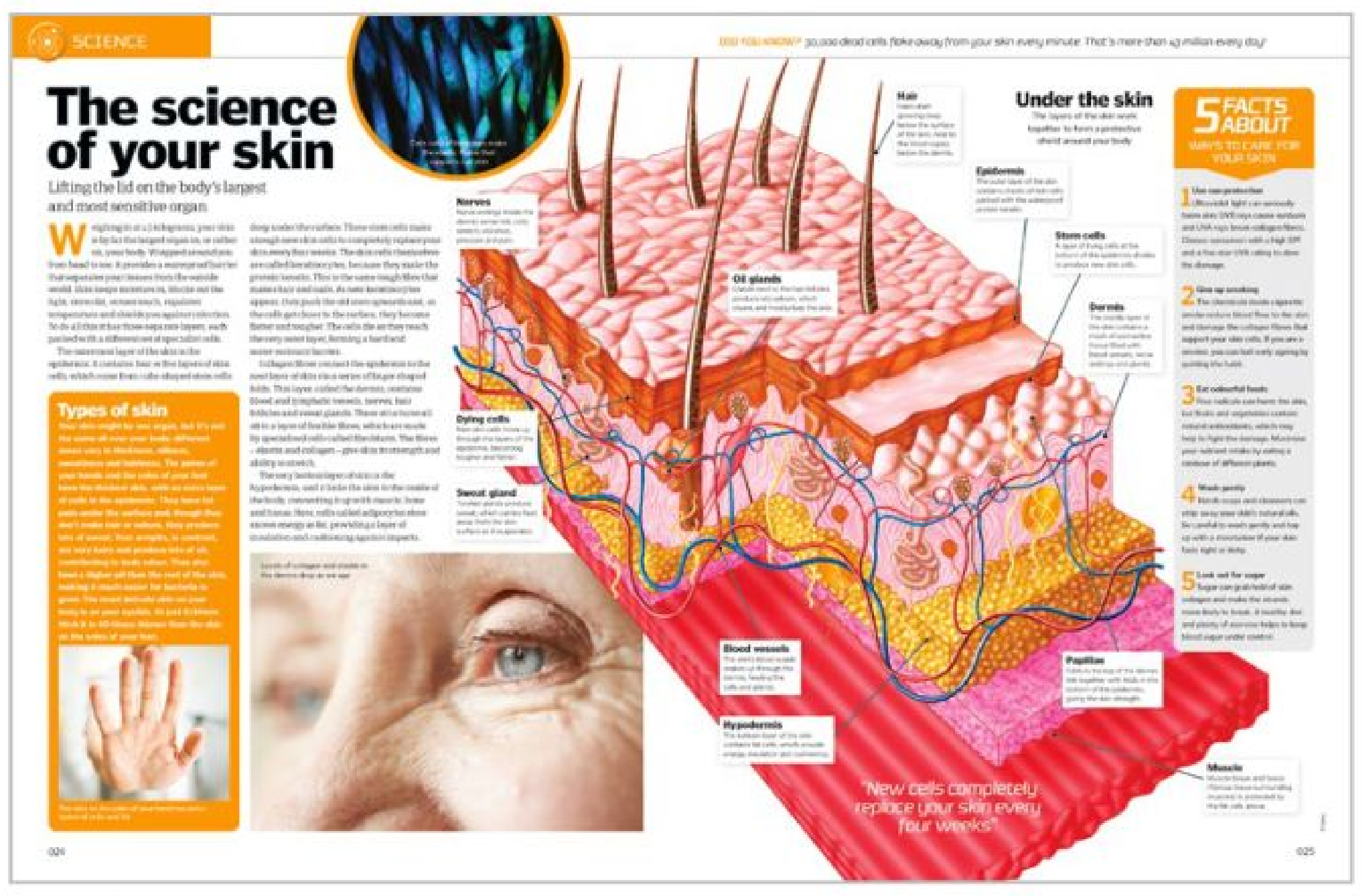
Magazines, back issues & bookazines.



HOW IT WORKS

AMAZING CUTAWAYS

Discover the inner workings of the world's wonders



SCIENCE

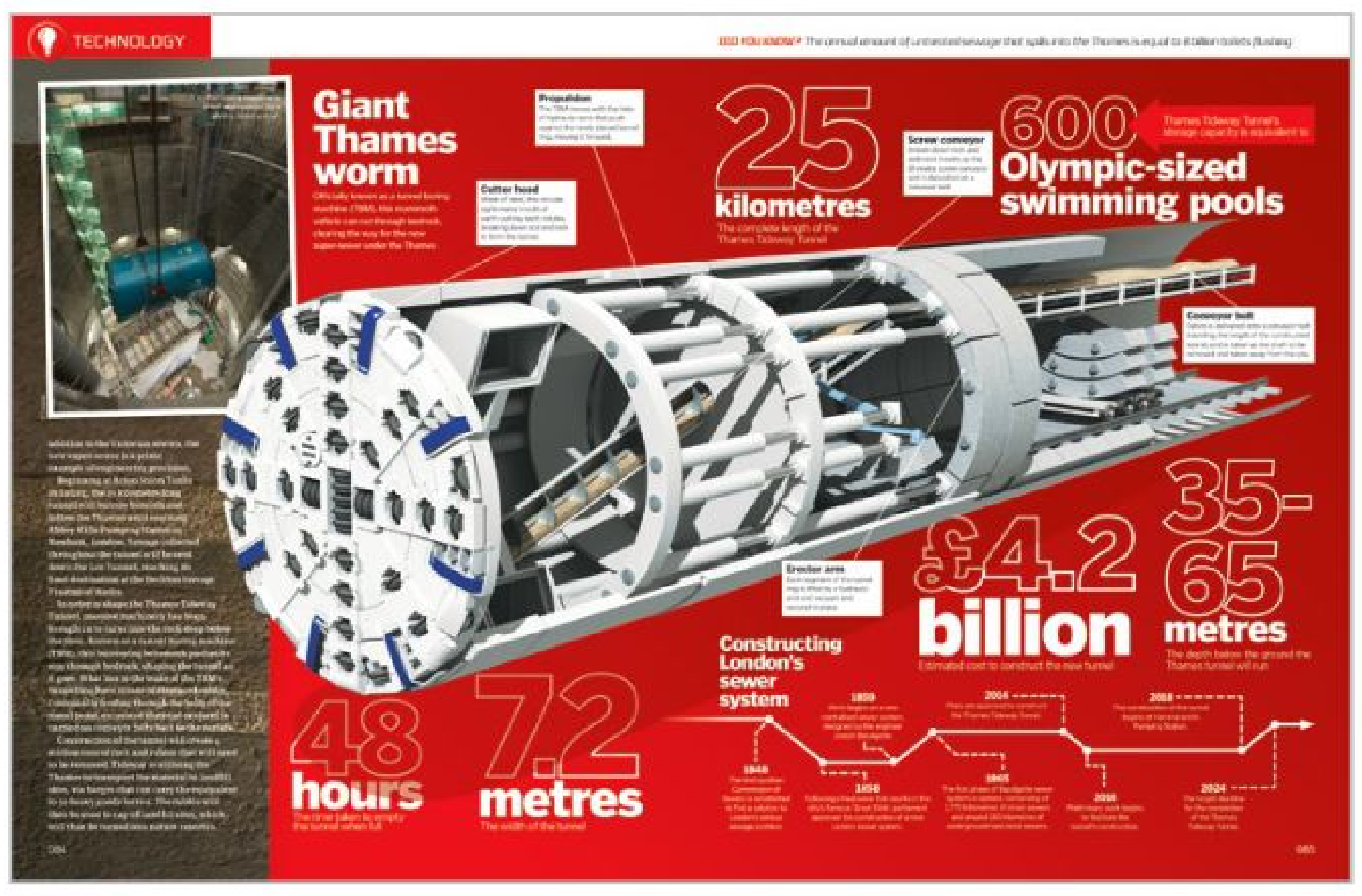
Find out what makes muscles strong, how the human body's digestive system works, what happened at Chernobyl and much more

TRANSPORT

From superyachts to superjets, get under the hood of some of the most innovative and fascinating vehicles on the planet

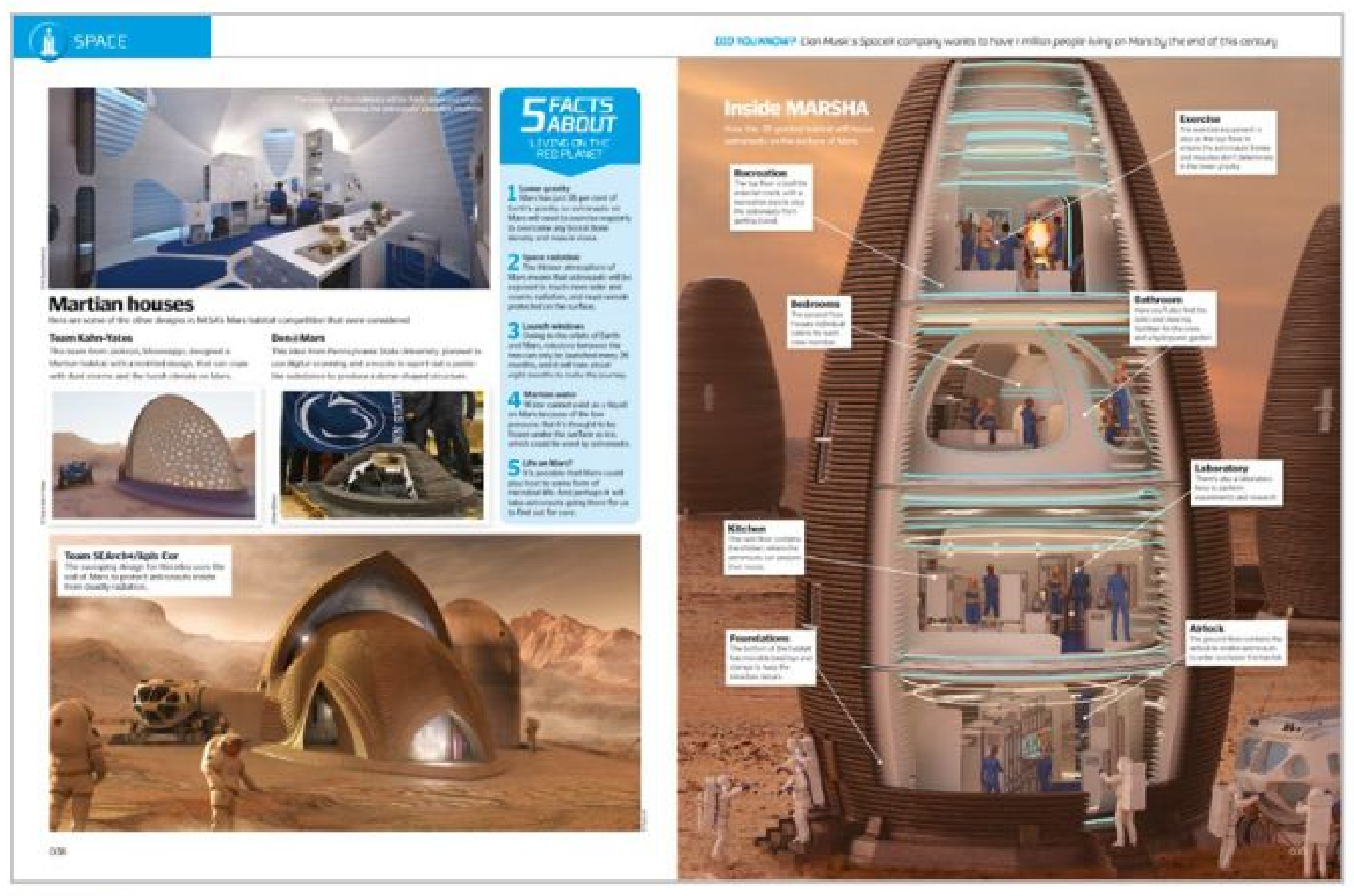
ENVIRONMENT

Take an in-depth look at the wonders of the natural world, such as the importance of trees and how bees make honey



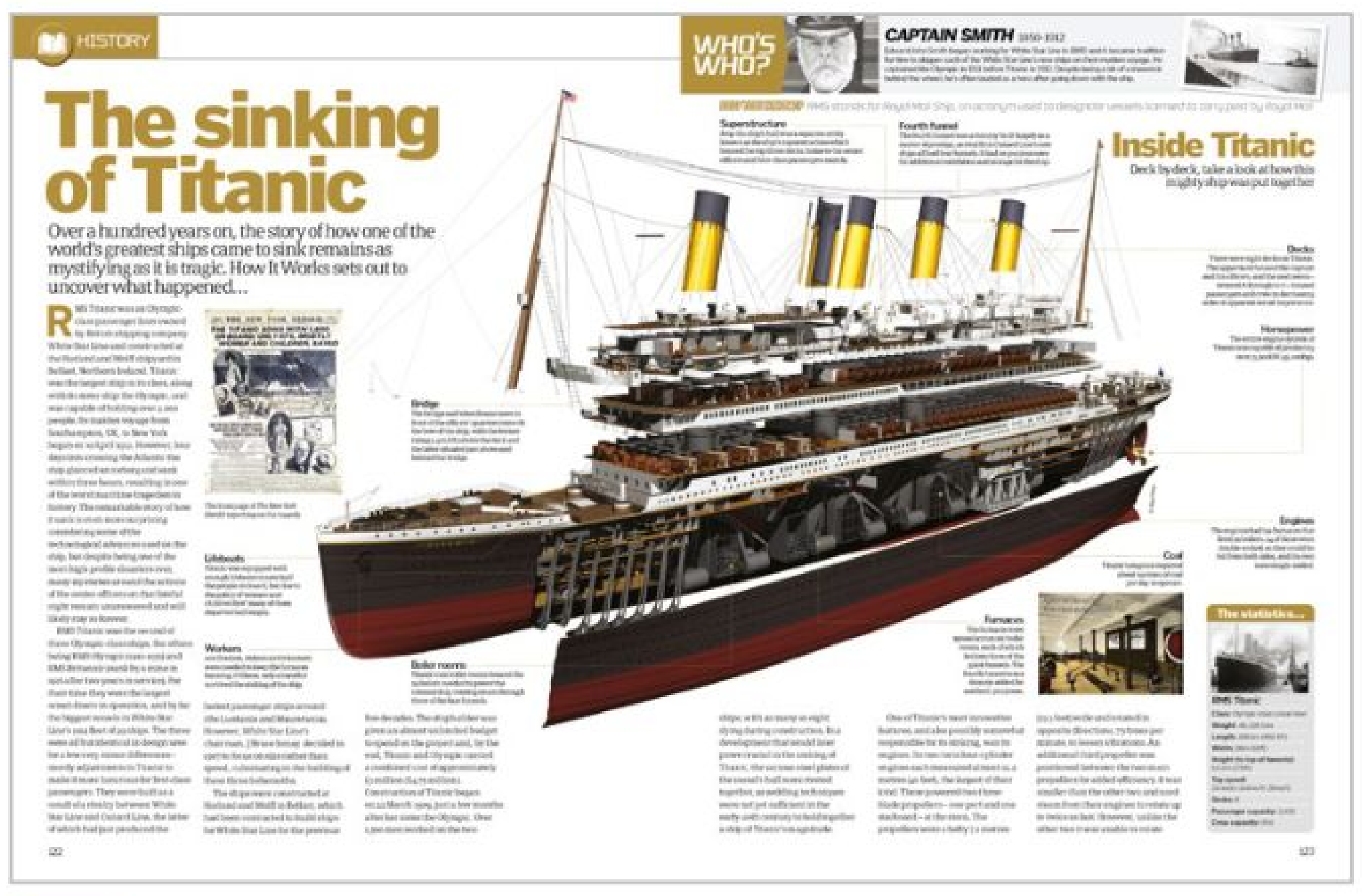
TECHNOLOGY

Step inside the smart home of the future, find out how CT scanners work and discover how stand mixers transformed the way we bake



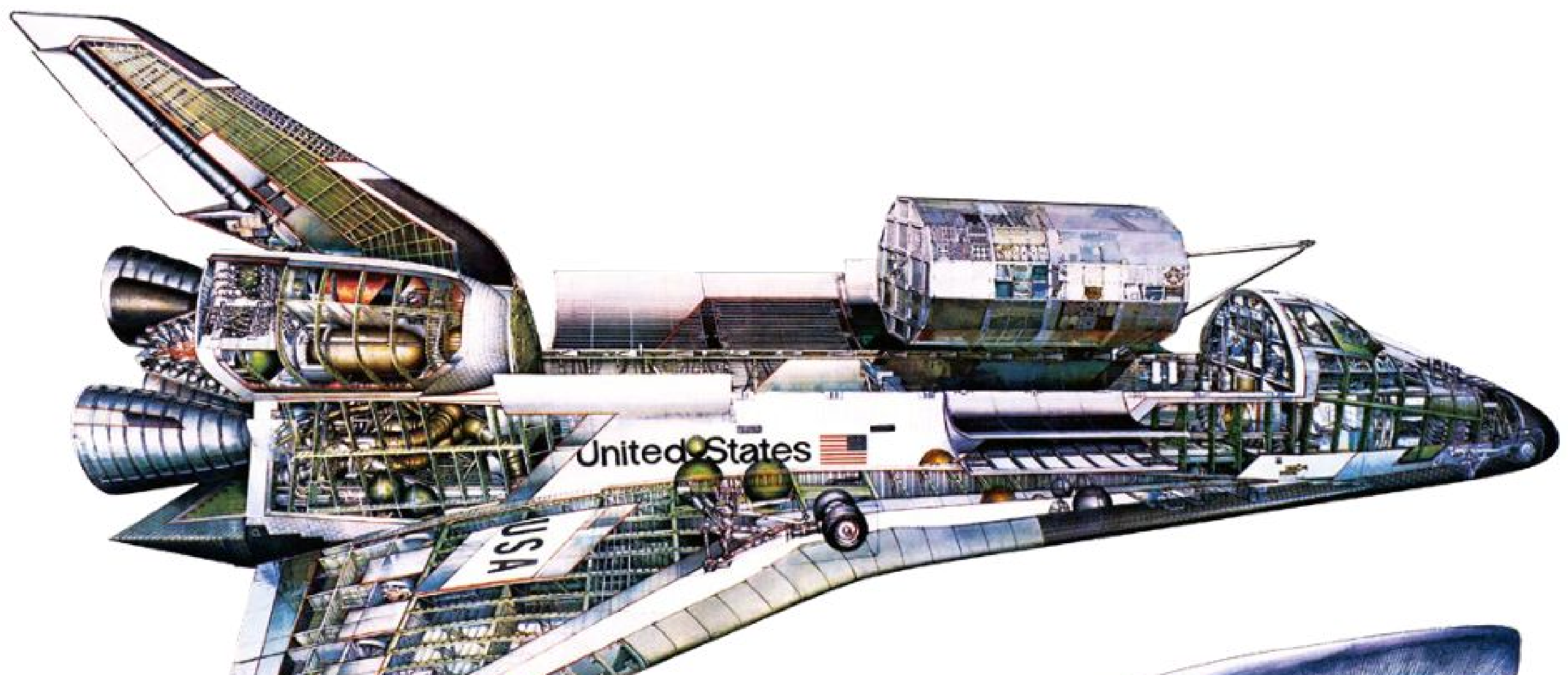
SPACE

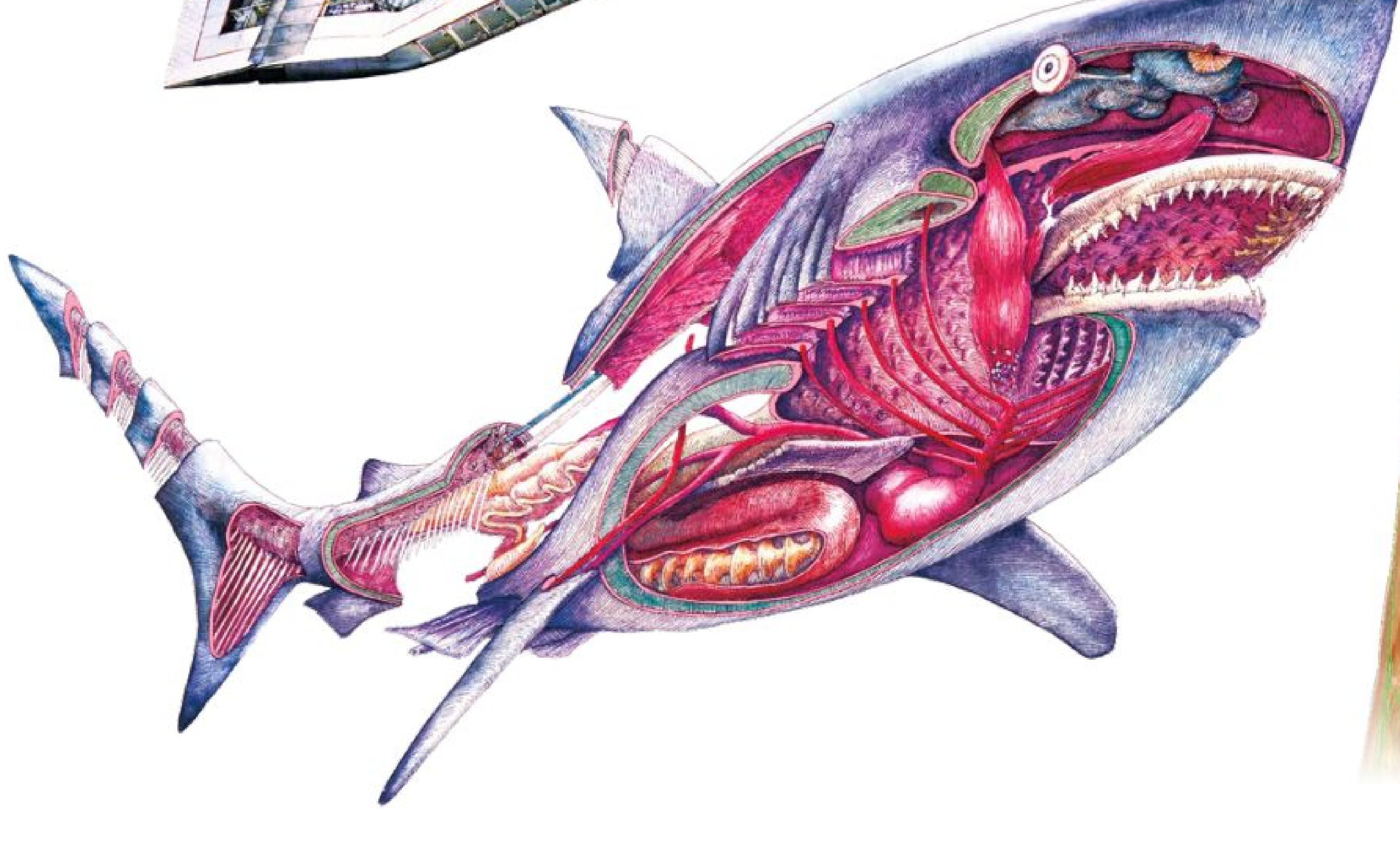
Explore the secrets of space, from how NASA's legendary Space Shuttle worked to the tech that could help humans survive on Mars

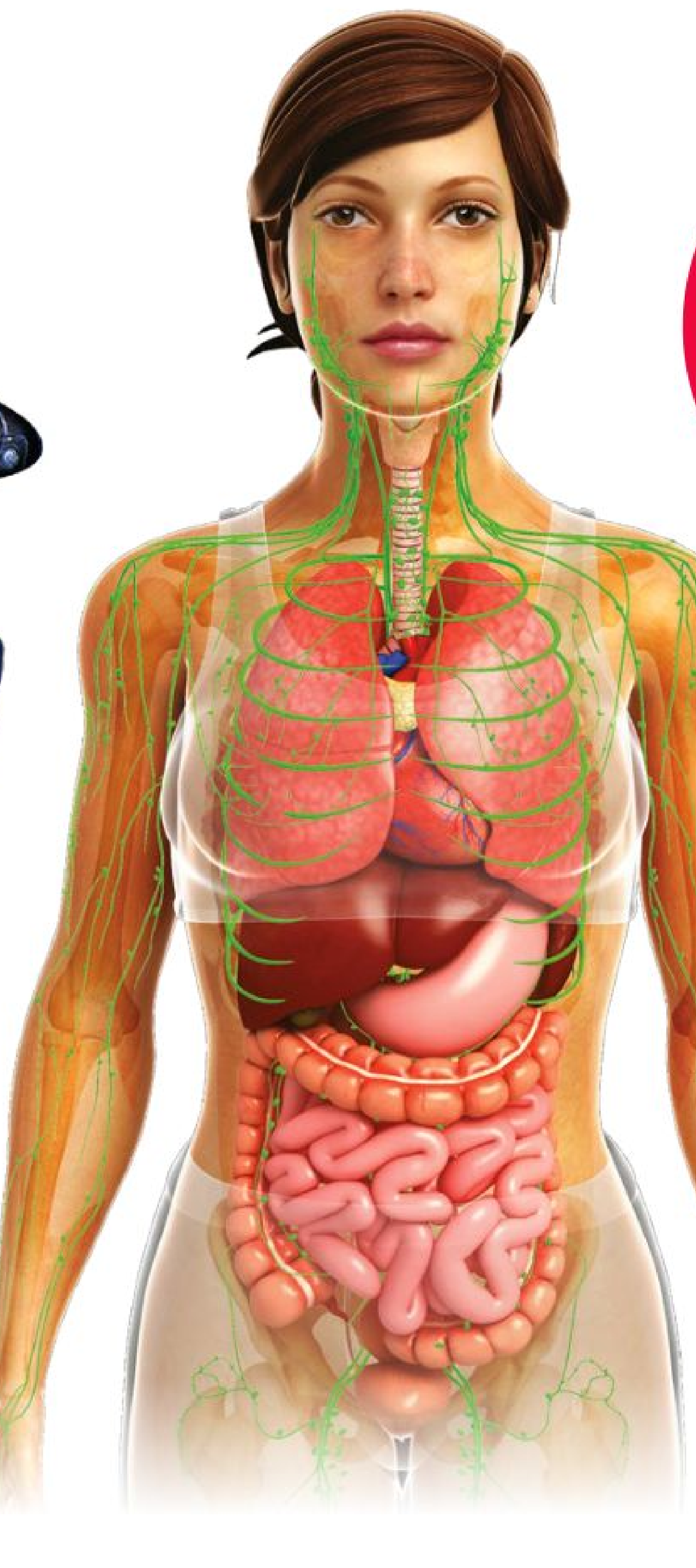


HISTORY

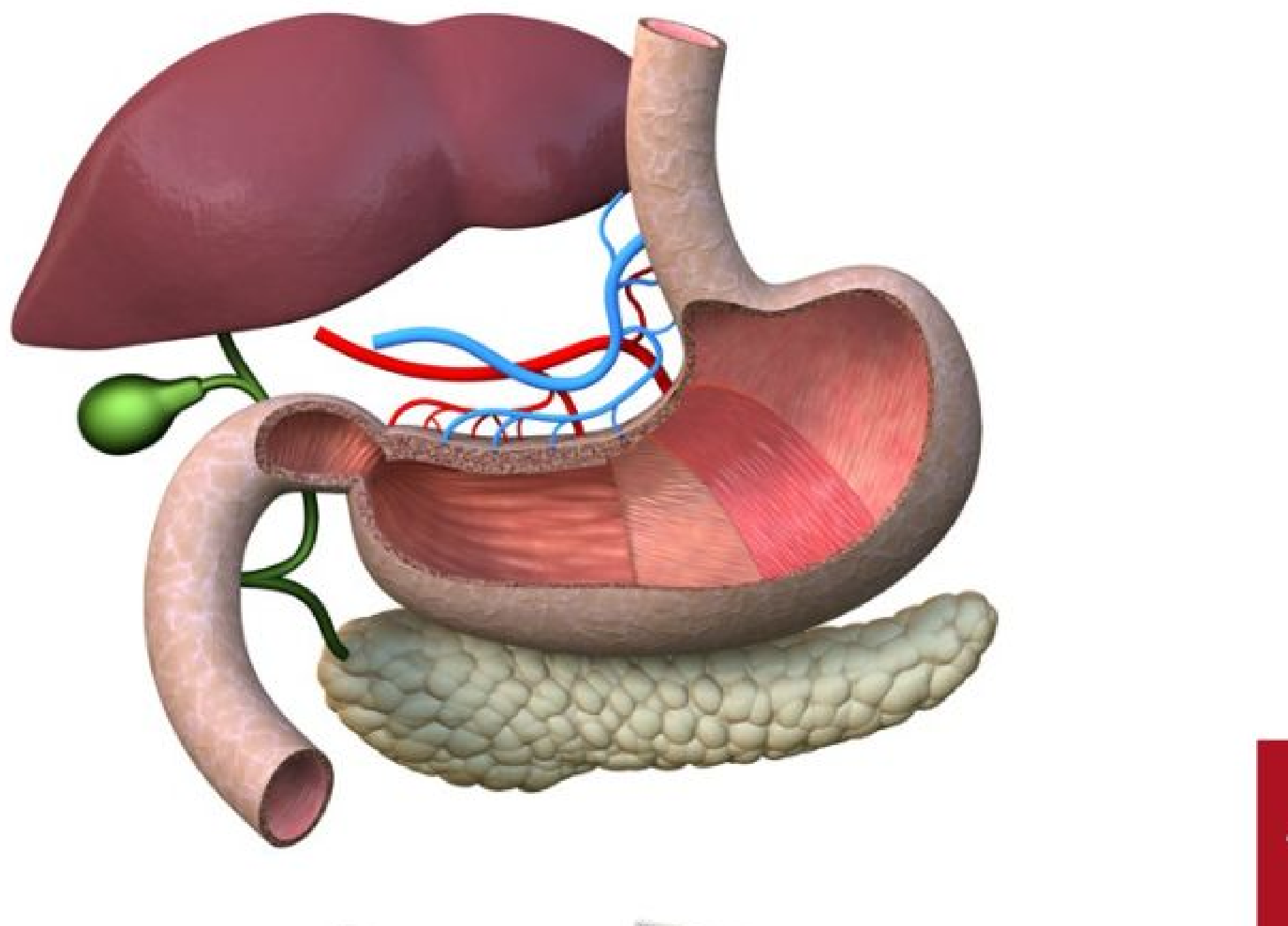
Revisit Henry VIII's historic royal residence, how Florence Cathedral's dome was built and go inside the iconic White House







INCREDIBLE ILLUSTRATIONS INSIDE



BOOKAZINE